APPENDIX K

(TEST PLAN AND TEST INSTRUMENTATION)

Submitted as part of the Final Report

for RF Test Console on JPL

Contract No. 950144

NAS 7-100

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WESTINGHOUSE DEFENSE AND SPACE CENTER

SURFACE DIVISION

ADVANCED DEVELOPMENT ENGINEERING

TEST EQUIPMENT

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A. Commercial Test Instrumentation

A survey of commercial test instrumentation was made to determine those instruments which would most suitably meet the requirements of the R.F. Test Console. The results of this survey are summarized in Tables 1 to 8. In these tables the instruments of various manufacturers are compared with regard to what are felt to be the most important characteristics. The recommended instruments are given below with the reasons for selection.

1. Frequency Counter

The Hewlett Packard 5245L frequency counter is recommended because of its superior stability and accuracy.

2. Sine Wave Oscillator

The Hewlett Packard #651A sine wave oscillator is recommended because of its low distortion, stability and flexibility.

3. Function Generator

The Wavetek #103 function generator is recommended because of its low distortion, range and flexibility.

4. Oscilloscope

The Tektronix #585 oscilloscope with a Type 82 plug-in is recommended because of its frequency response, sensitivity and availability of plug-in units.

5. Digital Voltmeter

The Hewlett Packard #3440A digital voltmeter is a good general purpose meter at a reasonable price.

TABLE 1

65-355 APP K

FREQUENCY COUNTER (ref. 3.5.5.1) a digital freq. counter up to 50mc

Characteristics	Hewlett Packard Palo Alto, Calif.	Hewlett Packard Palo Alto, Calif.	Systron Donner Concord, Calif.	Com dex Measurements San Fernando, Calif.	
Model	5245 L	5244 L	1037	300 w/802A	7270
Range	0 to 50mc	0 to 50mc	0 to 50mc	50cs to 50mc	0 to 50mc
Accuracy	± 1 count + time base accuracy	± 1 count + time base accuracy		± 1 count ± time base	± 1 count ± time base
Stability	± 3 parts in 10^9/day	± 2 parts in 10^7/mo.	± 1 parts 10^7/8hr.	± 3 parts in 10^9/day	± 5 parts in 10^9/hr.
Warm Up Time	*after 72 hrs		1 hr	after 10 days	after 2 hrs
Sensitivity	100mv rms	100mv rms	100mv rms	100mv rms	100mv
Input Impedance	10K, 40pf, 0.1v range	10K, 40pf, 0.1v		1m, 25pf	1m 2 50pf
Gate Time	1u sec to 10 sec	1u sec to 10 sec			1u sec 10 sec
Display Time	0.2 sec to 00	0.1 sec to 00		.2 sec to 00	.2 sec
Read Out	9 DIGITS	7 DIGITS	8 DIGITS	9 DIGITS	7 DIGITS
Read In	KC & MC w/decimal point	KC & MC w/decimal point			CPS, KC, MC
Plug Ins.	Available	None	Available	Available	
Power	90 watts	30 watts	100 watts	100 watts	75 watts
Size weight	16 3/4D x 5¼H x 1? 3/8W				
Price	$2905	$2225	$2550	$3010 w/802A	$2625

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TABLE 2

SINE WAVE OSCILLATOR (ref 3.5.5.2) to 1.5 mc

SPECIFICATION	Hewlett Packard Palo Alto, Calif.	Wayne Kerr Philadelphia, Pa.	Wave Forms New York, N. Y.
Model	651A	0-22A	402A
Frequency Range	10 cps to 10mc	10KC to 10mc	10cps to 15mc
Output Impedance	50 and 600 ohms, 75 ohms on request	75 ohms	600
Output Level	16mw(3.16v)into 600, 200mw(3.16v)into 50	2v into 10K, 160mw, 75	10mw into 600
Distortion	1% to 5mc, 2%@10mc	1%	10%
Stability	10 parts in 10^6 for 60 sec.	1 part in 10^3 hr	$\pm$ 5 parts in 10^5 short term
Output Monitor Accuracy	$\pm$ 2% of full scale, $\pm$ 1% to 10 mc	$\pm$ .5db	Output monitor
Output Attenuator	90db	60db	100db
Miscellaneous		50 output optionally available	
Power	20 watts		60 watts
Size and Weight	5 7/32H x 16 3/4 D		8 x 6 x 10½, 12#
Price	$590	$780	$350

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TABLE 3

FUNCTION GENERATOR (ref 3.5.5.3) Low-Frequency sine, square, & triangular waveforms

SPECIFICATION	Hewlett Packard Palo Alto, Calif.	Wavetek San Diego, Calif.
Model	202A	103
Frequency Range	.008 to 1200 cps	.008 to 1 MC
Wave Forms	sine, square, triangular	sine, square, triangular
Output Impedance	40 ohms	50 ohms & 600 ohms
Output Level	30^V P-P across 4000	30^V P-P into 600
Amplitude Stability		1% long term .1% short term
Frequency Stability	1%	1% long term .1% short term
Distortion sine triangular square	1% on x.01, x.1, x1, x10 freq. range 2% on x 100 range	1% to 10KC, 2% to 100 KC 1% for harmonics 1 mc tilt .1% overshoot 1% harmonics 10mc ringing 5% harmonics 10mc
Power	150 watts	5 watts
Weight	37#	8#
Size	19w x 10 15/32H x 13"D	7 3/4W x 5 1/8H x 7$\frac{1}{2}$D
Price	$535	$595

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TABLE 4

CSCI LOGGER (ref. 3.5.5.4) capable of directly viewing any signal generated

SPECIFICATION	Hewlett Packard Palo Alto, Calif.	Tektronix Portland, Oregon	Fairchild Clifton, N.J.
Model	175A	585	767A/?
Sweep Generator	w/1780A time unit		w/74-03 time base
range	.1u sec/cm to 5 sec	.05u sec/cm to 2sec/cm	.05u sec/div to 2 sec
accuracy	+ 3%	3%	3%
triggering	AC, DC, Int, Ext, Line	AC, DC, Int, Ext, Line	AC, DC, Int, Ext, Line
external triggering sensitivity	.5v ... 50 mc	.2v p-p	.25v lnc
jitter		2 parts in 10^4	
Vertical Amplifier	w/1750F dual trace	w/type 82 dual trace	w/79-02A dual trace
rise time	7 sec	4.2 sec	3.5 sec
pass band	50 mc	85 mc	100 mc
sensitivity	.05v/cm to 20v/cm	.01v/cm to 20v/cm	.01v/div to 20v/div
impedance (no probe)	1M & 23pf	1M & 12pf	1M & 14pf
Cathode Ray Tube & Phosphor	6 x 10 cm display P31 alumized phosphor	4 x 10 cm P31	6 x 10 cm P31
Graticle	internal	external	external (internal optional)
Plug In Capability	yes	yes	yes
Miscellaneous	requires time base plug-in 1780A $25	582 plug in at $650.00	requires time base unit 74-03A $45.00
Power	425 watt max.	630 watt max.	200 watt
Size weight	16 3/4H x 12¼H x 24 2/8D 70#	16 7/8H x 13 1/8W x 23 7/8D 67#	7"H x 20"D x 19" 27#
Price	$1675 + 25 = $1700.00	1725 + 650 = 2375	1970 + 345 = 2315

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TABLE 3

DIGITAL VOLTMETER (ref 3.5.5.5) digital dc voltmeter w/limited AC capabilities

SPECIFICATION	Hewlett Packard Palo Alto, Calif.	Hewlett Packard Palo Alto, Calif.	Cubic San Diego, Calif.	Cimron San Diego, Calif.
Model	3440A w/3442A plug-in	405BR	15-250	7200A
Display	4 Digits	3 Digits	5 Digits + range + polarity	5 Digits
Accuracy	±.05% ± 1 digit	±.02% ± 1 digit	±.001% ± 1 digit	±.01% ± 1 digit
Stability			.005%/month	
Ranges	3 ranges up to 999.9	3 ranges up to 999	3 up to 1000	3 to 999.99
Sample Rate	5 ranges/sec	4 or 5 per sec		
Input Impedance	10.2 M		10 M DC	1000M on 9.9999 range 11M 99.999 & 999.99
Response Time	450ms to a step function	1sec to a step function	.2sec max.	
Common Mode Rejection			130db DC 100db 60 cps	
Sensitivity				100 mv
A-C Capability to frequency	457 AC to DC converter 50 cps to 500 KC ($395)	w/457AC to DC converter 50 cps to 500 KC ($395)	w/PN 86-7100 35 cps to 5KC can measure ohms, remote operation	1200
Power	20 watt	180 watt		
Size & Weight	5¾H x 16 3/4W x 11½D 20#	7"H x 19"W x 13 7/8D 31#		
Price	1295 + 395 = 1690.00	$890 + 395 = 1285	3990 + conv	3400 + 1200 = 4600

TABLE 6

... measure ratio noise variance S/N (ref. 3.5.5.6)

SPECIFICATION	Hewlett Packard Palo Alto, Calif.	Keithley Cleveland, Ohio	Fluke Seattle, Wash.
Model	400A	121	910A
Frequency Range	10 cps to 3 mc	15 cps to 50 mc	10 cps to 7 mc
Range	100 uv to 300 v	100 uv to 300 v	10 uv to 300 v
Accuracy	± 1% 50 cps to 3 mc ± 2% 10 cps to 3 mc	± 1% 20 cps to 10 mc ± 3% 15 cps to 20 mc	± 1% 50 cps to 2 mc ± 2% 20 cps to 2 mc
Meter Response Time	2 sec	1 second	
Crest Factor	3 to 1 full scale 10 to 1	3 to 1 full scale 12½	3 to 1 full scale
Input Impedance	10K @ 25 pf	1M @ 20 pf	10K @ 20 pf
Meter	2 linear db scales 0 to 3 & 0 to 10 1 log db scale -12 to +2	2 linear db scale 0 to 3 0 to 10 1 log db scale -12 to +2	3 scales
Miscellaneous		AC output .100 mv rms 6 rise time DC output 100 mv Cathode Follower probe available 10 meg, 15 pf	
Power	7 watts	50 watts	
Size & Weight	6½W x 5¼H x 11"D	17½H x 7¼W x 13 1/3D 17lb	19"W x 5¼H x 12½D
Price	$525	$370	$545

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TABLE 7

SPECTRUM ANALYZER (ref. 3.5.1.2 & 3.5.5.7) measuring spectral components - possible to translate the spectrum

SPECIFICATION	Hewlett Packard Palo Alto, Calif.	Airmec England	Singer-Metrics Bridgeport, Conn.
Model	310	853	Panalyzer SB-12
Frequency Range	15 to 1.5mc w/200 cps b.w. 50 to 1.5mc w/100 ... 100 to 1.5mc w/30C ...	30KC to 30mc	500 KC center frequency
Sensitivity	10 uv	1 uv	200 uv w/.3ᵛ rms conversion gain
Selectivity	3db @ 200cps w/200cps b.w.	as low as 10 cps	as low as 10 cps
Frequency Accuracy	±(1% + 300 cps) w AFC linear read w/1 div/200cps	± 1%	marker at 5KC intervals
Voltage Accuracy	± 5%	calibration charts supplied	± 5% bandpass flatness
Dynamic Range	75 db	70 db	60 db
Input Impedance	10K	75	
Spurious & Noise Response	-75db		
Accessories	sweep drive	probe	
Miscellaneous			scale-log linear sweep rate 0.1 to 30 cps requires external frequency converting local oscillator
Power	10 watts	70 watts	190 watts
Size & Weight	16 3/4W x 10½H x 18 3/8D	19"W x 16"H x 8½D	18½H x 19"W x 11½D
Price	$2200	$550	$1375

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TABLE 8

SPECTRUM DISPLAY (ref. 3.5.4.2 & 3.5.5.7) display transmitted spectrum 50 ± 1.5 mc

SPEC. DISPLAY	Hewlett Packard Palo Alto, Calif.	Singer Metrics Bridgeport, Connecticut	Singer Metrics Bridgeport, Conn.
Model	851A/8551A	Panalyzer SB - 8b2 type T100000	SPA-3a
Frequency Range	10mc to 40 GC	30mc center frequency	1KC to 15mc
Scanning Modes	linear ±5%	linear, line, external	linear, line
Sweep Widths	100KC to 20C	0 to 10mc	0 to 3mc
Resolution	1KC to 1mc	9KC to 30KC	200 cps to 20KC
Frequency Separation		35KC	2.2 KC
Sensitivity	-95 dbm	100mv w/.1^V rms conversion signal	25 uv to 1.1v
Amplitude Scale	log, linear, & square (power)	log, linear, & square (power)	log, linear
Amplitude Response	±1db any 200 mc B.W.	±15%	±15% to max cent freq.
Input Impedance			75 , 50
Sweep Repetition Rate	3m sec/cm to 1 sec/cm	1 to 60 sweep/sec	1 to 60/sec
Internal Marker			50KC & 500KC xtal
CRT	P2 (others optional) internal graticule	5" 5ADP7	5ADP7
Misc.	complete as is	w/ external oscillator	requires external oscillator
Power	275 watts	150	180
Size & Weight (both)	18 3/8D x 16 3/4W x 20"H 130#		21½H x 19"W x 21"D
Price	$9500	$1500	$3400

6. True RMS Voltmeter

The Keithley 121 True RMS Voltmeter is recommended because of its frequency range and accuracy.

7. Spectrum Analyzer

The Hewlett Packard 310 Spectrum Analyzer has adequate frequency range coupled with good resolution, sensitivity and low spurious response.

8. Spectrum Display

Although the Singer-Metric SPA-3a requires an external oscillator and mixer to down-convert the 50 mc signal to 15 mc, it has the advantages of good resolution, bandwidth and sensitivity.

If no test equipment other than that specified will be available for use with the R.F. Test Console, consideration should be given to the procurement of some additional items, such as a recorder for the frequency counter, a camera for use with the oscilloscope and spectrum display, an r.f. signal generator, a power meter, and r.f. millivolt-meter, a differential voltmeter, a communications receiver and miscellaneous test equipment such as multimeters, bridges, etc.

F. Special Test Instrumentation

At present, it appears that very little special test instrumentation will be required. The major items will be mixers for up-converting and down-converting the 50 mc signal and at least one external frequency source. These items and their application are summarized below:

1. A mixer for up-converting the 50 mc signal to 70 mc so that the Marconi Modem Test Set MQ-26A can be used as a standard demodulator for checking the transmitters. A local oscillator source of 120 mc is also

required but it is felt that a commercial signal generator can be used for this application since the mixer is required only for unit tests.

2. A down-converter and local oscillator will be required for use with the Spectrum Display. For the down-converter, it appears that the General Radio 874-MR is satisfactory and will meet the requirements of this application. A 65 mc local oscillator will be required.

3. In addition to the above, there may be some items which will be required for special test setups, such as directional couplers, power dividers and etc.

Addendum to Test Equipment

9. Power Meter

The General Microwave 450 A Power Meter is recommended because of its scale resolution. High resolution is required in setting up the linear S/N summer. Table 9 summarizes the characteristics of the instruments surveyed.

TABLE 9
POWER METER

SPECIFICATION	HEWLETT PACKARD Palo Alto, Calif.	FXR Woodside, N. Y.	GENERAL MICROWAVE Farmingdale, Long Island, N. Y.	
Model	431 B	B833A	450A	454A
Range	7 ranges Full scale readings, 10 microwatt to 10 MW (-20dbm to + 10 dbm)	4 ranges Full scale readings, 10 microwatt to 10MW (-20dbm to + 10dbm)	5 ranges .100 MW to 10 MW (-10dbm to 10dbm)	13 ranges *.3 W to 300 MW (-45dbm to +25dbm)
Accuracy	3%(20-35°C); 5%(0-55°C)	3% (15-35°C); 5% (0-50°C)	5%	1%
Thermal Drift			2 w/°C	.1%/°C
Zero Carryover	1% of full scale when zeroed on most sensitive range	Yes		Yes
Operating Impedance	100 or 200 ohms, negative		100 ohm negative	
VSWR	1.3 25mc - 10gc	1.5 10MC-12.4 gc	1.5 .01-10 gc	1.5, .01-10 gc
Drift				
Scale Resolution			1% of full scale	1.5 nanowatts
Miscellaneous	Recorder/Voltmeter Output	Provision for external potentiometer devices, recorder output		Recorder/voltmeter output
	Requires 478A thermistor mount	Requires N218C Thermistor mount	Requires N400 Thermistor Mount	Requires Thermist mount
Power	2.5 W, 115/230 V ± 10%, 50 to 1000 cps.	12 W, 115/230 V + 10% 50 - 60 cps.	55 W, 115/230 V±10% 50-1000 cps.	30W, 115/230 V 60 cps.
Size & Weight	7 25/32 "W x 12½" L x 6⁵/8"H;8#	13"W x 8½" L x 6"H; 15#	7½"W x 14" Lx11½"H; 18#	7½"Wx14"Lx11 1/2 "H;19#
Price	$425. + 145 = $570.00	$495. + 150 = $645	$495 + 150 = $645	$475 + 175 = $650

* With N420 Thermistor mount, 3 W to 30 MW

Outline For

Test Plan For R.F. Test Console

A. GENERAL

B. FREQUENCY SYNTHESIZER

    1. Short Term Stability Test

    2. Long Term Stability Test

C. PM TRANSMITTER/RECEIVER

    1. PM Transmitter

        a. General

            (1) Frequency

            (2) Power Output

            (3) Frequency Multipliers & Reference Output

            (4) Bandwidth

        b. Phase Modulator

            (1) Frequency Response

            (2) Phase Deviation

            (3) Deviation Linearity

            (4) Incidental AM

        c. Amplitude Modulator

            (1) Frequency Response

            (2) Percent Modulation

            (3) Modulation Linearity

            (4) Incidental FM & PM

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2. PM Receiver

   a. General

   b.* Input amplifier

      (1) Bandwidth

      (2) Phase linearity

   c.* Voltage Controlled Oscillator

      (1) Frequency

      (2) Stability

      (3) Manual Tuning

      (4) Locked Condition

   d.* Balanced Modulators

      (1) Spurious & Carrier rejection

   e.* IF Amplifiers

      (1) Frequency response

      (2) Phase response

   f.* Reference Oscillator

      (1) Frequency & Phase Stability

   g. Phase Detectors

      (1) Bandwidth

      (2) Fidelity

      (3) Gain Constant

      (4) Phase Adjustment

   h. Phase Loop

      (1) Gain

         (a) Static Phase Error

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(b) Gain Stability

(2) Filter Bandwidth and Response

i. Amplitude Detectors

(1) Bandwidth

(2) Linearity

(3) Phase adjustment & manual gain control

j. AGC

(1) Loop Gain

(2) Filters

k. Offset Frequency

l. DC & AC Isolation amplifiers & PM predetection playback

3. PM Transmitter/Receiver Pair

a. Phase Stability

b. Fidelity

4. Phase Noise Instrumentation

D. FM TRANSMITTER/RECEIVER

1. FM Transmitter

a. General

(1) Transmitter Center Frequency

(2) Power Output

(3) Frequency Multipliers & Reference Output

(4) AFC Operation

(5) Bandwidth

b. Frequency Modulator

(1) Response & Sensitivity

(2) Frequency deviation

        (3) Deviation Linearity

        (4) Incidental AM

    c. Amplitude Modulator

2. FM Receiver

    a. General

    b. Input Filter

        (1) Bandwidths

        (2) Amplitude Characteristics

        (3) Linearity

    c. Limiter

        (1) Dynamic Range

        (2) Waveform

    d. Conventional FM detector

    e. Phase Lock FM Detector

        (1) Voltage controlled oscillator

        (2) Phase detector

        (3) Loop gain

        (4) Loop filter

    f. *Output filter

        (1) Response and Bandwidth

    g. Offset Frequency

    h.* Balanced Modulator

    i.* DC & AC Isolation amplifiers & FM predetection
        playback

3. FM Transmitter/Receiver Pair

    a. Frequency Stability

b. Static Linearity

c. Dynamic Linearity

E. LINEAR S/N ADDER   (Section IV)

F. MISCELLANEOUS

    1. Purchased Instrumentation

    2. Console Assembly Equipment

    3. Interference

TEST PLAN

A. General

This test plan describes the type of tests   the test measurements
to provide performance data of the completed assemblies. In some cases,
two types of tests will be used for comparison purposes. Tests of the
individual items for bandwidth, response and etc., will be made and
documented by the designer of the specific components, using the test
setups needed to achieve the level of performance. This will require
comparison methods and use of a calibrated reference, such as the
Weinschel Engineering high precision attenuators and dual channel
measuring setup. In some of the steps, a meter is shown as the in-
dicator. If this is not accurate enough, the meter will be used only
as a detector and the Weinschel dual channel system will be used as
the method for comparison.

Those tests which are starred (*) are appropriately unit tests and
they are listed for completeness.

B. Frequency Synthesizer

Since a number of the frequencies which are used throughout the
console are derived in the frequency synthesizer, the determination
of stability of the reference as well as the multiplied frequencies
is of the greatest importance.

1. Short Term Stability Test

The short term stability of a crystal oscillator is, at the
longer averaging times, predominantly controlled by oscillator defects
and, for very short averaging times, approaches the limits set by the

thermal noise of the crystal. i^1 has shown that the frequency deviation

$$\frac{\Delta f}{f} = \frac{2\pi}{\tau f_0} \sqrt{\frac{4KTB}{P}} \qquad (1)$$

where

τ = averaging time

f_0 = oscillator frequency

K = Boltzman's constant

T = absolute temperature

B = bandwidth of network

P = crystal driving power

As can be seen the frequency deviation is inversely proportional to the averaging time. Although no accepted standards exist for the specification of short term stability, the method most suitable for the evaluation of the oscillator performance is to specify the standard deviation, σ , for a specified confidence level. Phase deviation can be computed from the frequency deviation by the relation

$$\Delta \varphi (radians) = (2\pi f)\left(\frac{\Delta f}{f}\right)\tau \qquad (2)$$

Short term stability tests have already been made. The method, repeated here, was covered in the May 1964 Monthly Status Letter.

1MC Frequency Standard and X5, X2, X2 Frequency Multipliers

The short term stability of the 1MC standard was measured as indicated in figure 1.

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1. E. Hafner "Stability of Crystal Oscillators", Proc. 14th Annual Symposium on Frequency Control, 1960 p. 192-199.
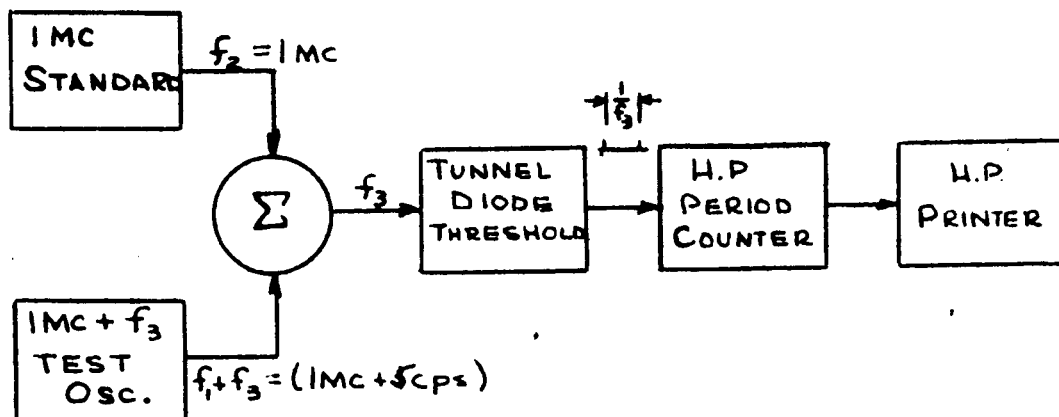
Figure 1. Oscillator Short Term
Stability Test Set

The oscillator under test, f_1, is offset from a 1mc standard, f_2, with known short term stability characteristics by an arbitrary frequency, f_3. The two oscillator outputs are linearly summed, envelope detected and the resultant threshold-detected with a low noise tunnel diode. The difference frequency (f_3) is converted to an impulse whose pulse repetition time (PRT) is $\frac{1}{f_3}$ plus the oscillator's short term instabilities.

The period counter counts the time between pulses, $\frac{1}{f_3}$. The variation in count is a dimensionless number which is a measure of the oscillator's short term instabilities as expressed by: $\frac{\Delta\ count}{counter\ capacity} \times \frac{f_3}{f_1}$. For example, if $f_3 = 5$ cps, counter capacity = 6 place and Δ count = 4, then, the short term stability $= \frac{4}{200,000} \cdot \frac{5}{10^6} = 1$ part in 10^{-10}.

The Δ count is printed for alternate 200,000 usec periods and may be read out as peak Δ count or computed as RMS. One hundred printed samples were taken to enhance the confidence level in either the peak or RMS Δ count levels.

This technique yielded a short term stability of 1.6 parts in 10^{-11} (RMS) referred to 1 sec integration time. The 1 second integration time was chosen, as a loop with 2 BLO of 3 cps will perform virtually no correction on a 1 cps input. The relationship of the dimensionless number of 1.6 parts in 10^{-11} (RMS) to degrees of phase jitter ($\Delta \varphi$) at 50 mc is outlined as follows:

$$\Delta \varphi \ (degrees) = (2\pi f)\left(\frac{\Delta f}{f}\right) \times \tau \times 57.3$$

$$= \left(2\pi \times 50 \times 10^{6}\right)\left(1.6 \times 10^{-11}\right)\left(1 \ second\right) \times 57.3$$

$$= .288^{\circ} \ nms \ phase \ jitter$$

This technique may be of interest but it does not provide an easily interpreted measure of performance when compared to the JPL spec.: namely, 3 degrees peak phase error in a noise free coherent receiver with 2BL of 3.0 cps. Therefore, $1-H(S)$ $\left[\dfrac{e(s)}{\theta_i(s)}\right]$ was mechanized on the analog computer as follows:

$$\frac{e(s)}{\theta_i(s)} = \frac{s^2}{s^2 + \sqrt{2}\,\beta_0 s + \beta_0^2}$$

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or $\quad e(s) = \Theta_i(s) - \dfrac{e(s)}{s}\sqrt{2}\,B_0 - \dfrac{e(s)}{s^2}B_0^2$

scaling: $\quad 2BL_0 = 3 = 6.6\,f_0, \quad f_0 = \dfrac{B_0}{2\pi}$

$\qquad B_0 = \dfrac{3 \times 2\pi}{6.6} = 2.86 \;\; \text{RAD/SEC}$

$\qquad B_c^2 = 8.21 \; [\text{RAD/SEC}]^2$
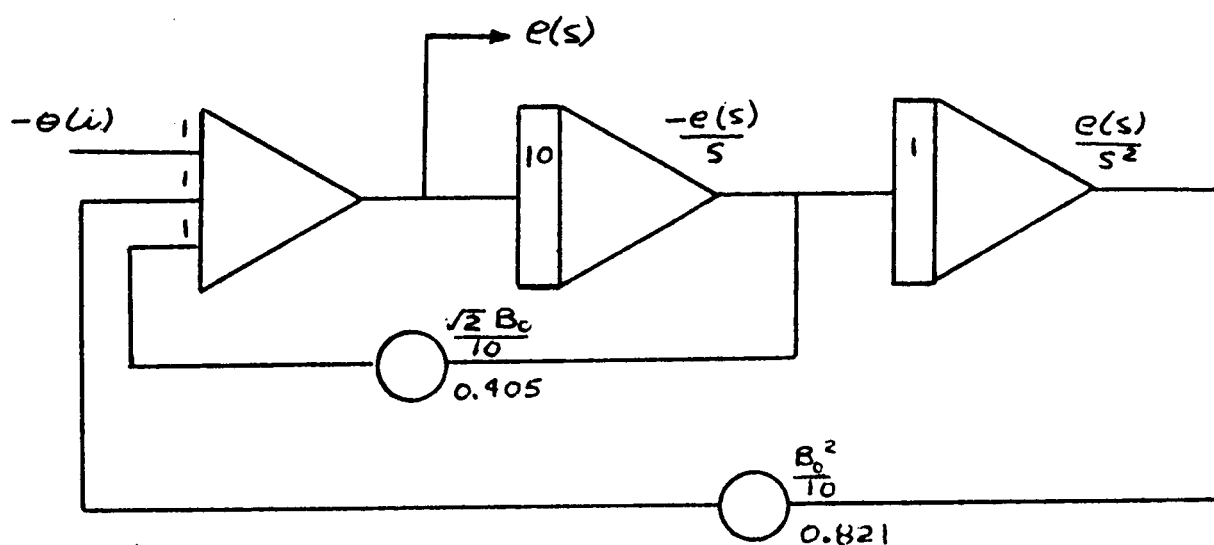
$\qquad \sqrt{2}\,B_0 = 4.05 \; [\text{RAD/SEC}]$

Figure 2. Analog Computer Simulation

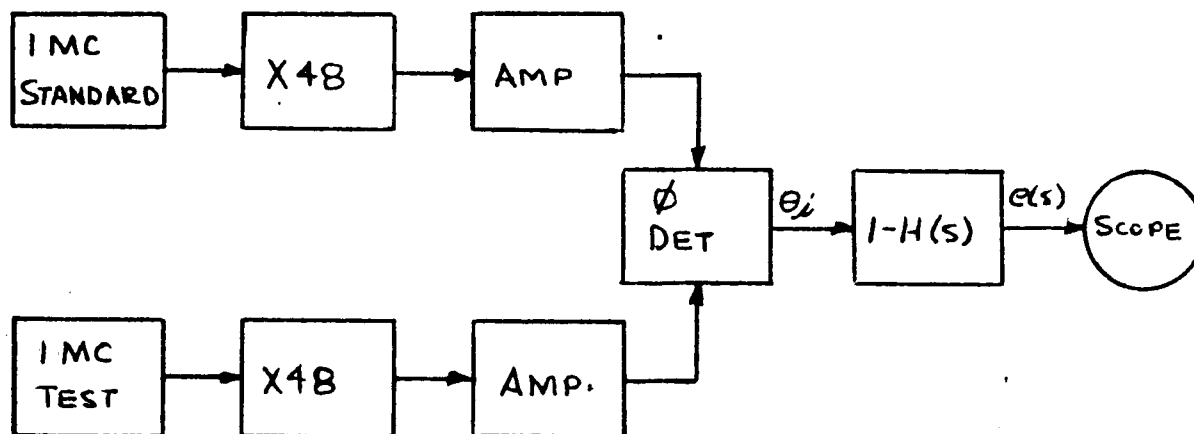Further, the oscillators (test and standard) were organized as follows:

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Figure 3. Oscillator Short Term Stability Test with Simulated
$2 \mathrm{BL}_{\mathrm{o}} = 3.0$ cps

Initially, the oscillators were offset to calibrate the scope in $\dfrac{\text{volts}}{\text{radian}}$.

The oscillators were tuned to zero beat and the phase noise in $2\mathrm{BL}_{\mathrm{o}}$ of 3 cps measured on the scope as 1.43 degrees peak i.e. truly, "peak" is meaningless in a statistical sense as pointed out by Mr. Frank Charles; however, this was the "grass level" viewed on the scope. Secondly, the system was connected as follows:
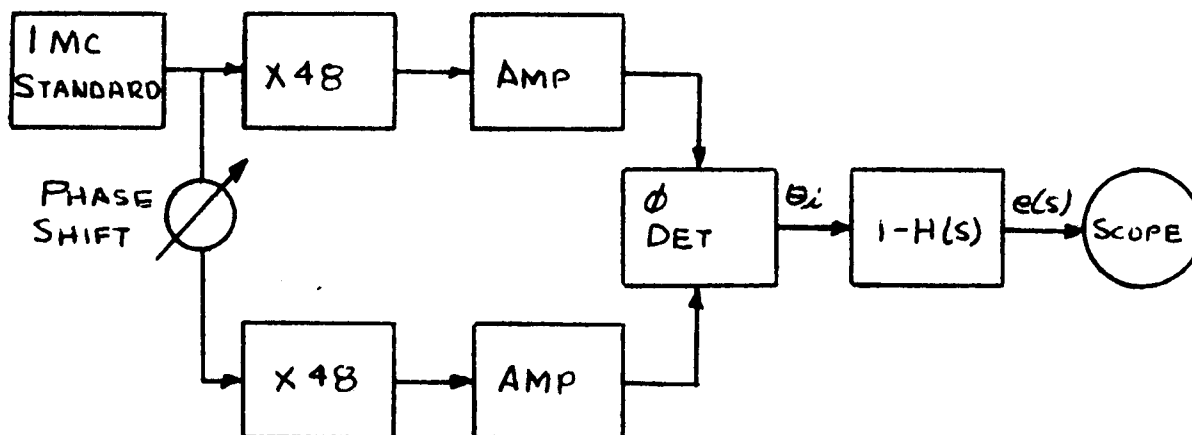
Figure 4. Multiplier, Amplifier, Phase Detector Short
Term Stability Test

$J_o(\beta)$, as seen on the spectrum analyzer disappears. (This can also be monitored by the carrier suppression measurement equipment if available). This represents the first carrier null and occurs for a modulation index β = 2.4048. Data is then taken of the voltage needed to null the carrier as a function of modulating frequency. A curve is then plotted as shown in figure 6. For phase modulation, $\beta = \Delta\theta$ and so changes in modulating frequency will only spread the sidebands and not change the level or their number, since $\Delta\theta$ is not being changed. Response will also be checked for other deviations, such as $\beta = 3.8$ for the first sideband null.

At deviations below 2.4048, the response should be good and there should be no tendency to clip off the sidebands. Consequently, if the response is good at 2.4, it should be good at lower B's, and,

$$\frac{\beta_x}{\beta_{2.4}} = \frac{V_x}{V_{2.4}}$$

A check of the response at modulation indices less than 2.4 will be made by means of a spectrum analyzer. Since the carrier and first sidelobe amplitudes are functions of β, their ratio is a measure of the modulation index. As the β is reduced, the ratio can be measured and the modulation index found from tables or curves. The measurement will be made by means of a reference generator and a precision attenuator in which its output level is matched to the levels of the carrier and sidebands.

C. PM Transmitter/Receiver

1. PM Transmitter

a. General

Input-output characteristics of the transmitter, such as impedances and levels will be measured. The impedances will be measured with an RF bridge such as the General Radio 1606A or the Boonton 250A RX Meter. Measurements with these instruments can be made to accuracies within 2-3% at 50 mc. Levels will be measured with a power meter, the Hewlett Packard 431B. This is a very stable instrument and measurement accuracies of 3% are attainable.

(1) Transmitter Center Frequency

This is a demonstration of capability and will be verified with a frequency counter such as the HP5245L. A measurement accuracy of $\pm$ 1 count $\pm$ 3 parts in 10^9 per day can be obtained with this instrument.

(2) Power Output (covered above)

(3) Frequency Multipliers and Reference Output

This was covered in Section B.

(4) Bandwidth

Bandwidth and frequency response will be determined by the setup shown in figure 6. An audio oscillator is used to modulate the phase modulator and a spectrum analyzer or a narrow band receiver is used to monitor the output.

With the modulating frequency of the oscillator at a low value, the output voltage V of the oscillator is adjusted until the carrier,

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$J_o(\beta)$, as seen on the spectrum analyzer disappears. (This can also be monitored by the carrier suppression measurement equipment if available). This represents the first carrier null and occurs for a modulation index β = 2.4048. Data is then taken of the voltage needed to null the carrier as a function of modulating frequency. A curve is then plotted as shown in figure 6. For phase modulation, $\beta = \Delta\Theta$ and so changes in modulating frequency will only spread the sidebands and not change the level or their number, since $\Delta\Theta$ is not being changed. Response will also be checked for other deviations, such as β = 3.8 for the first sideband null.

At deviations below 2.4048, the response should be good and there should be no tendency to clip off the sidebands. Consequently, if the response is good at 2.4, it should be good at lower B's, and,

$$\frac{\beta_x}{\beta_{2.4}} = \frac{V_x}{V_{2.4}}$$

A check of the response at modulation indices less than 2.4 will be made by means of a spectrum analyzer. Since the carrier and first sidelobe amplitudes are functions of β, their ratio is a measure of the modulation index. As the β is reduced, the ratio can be measured and the modulation index found from tables or curves. The measurement will be made by means of a reference generator and a precision attenuator in which its output level is matched to the levels of the carrier and sidebands.
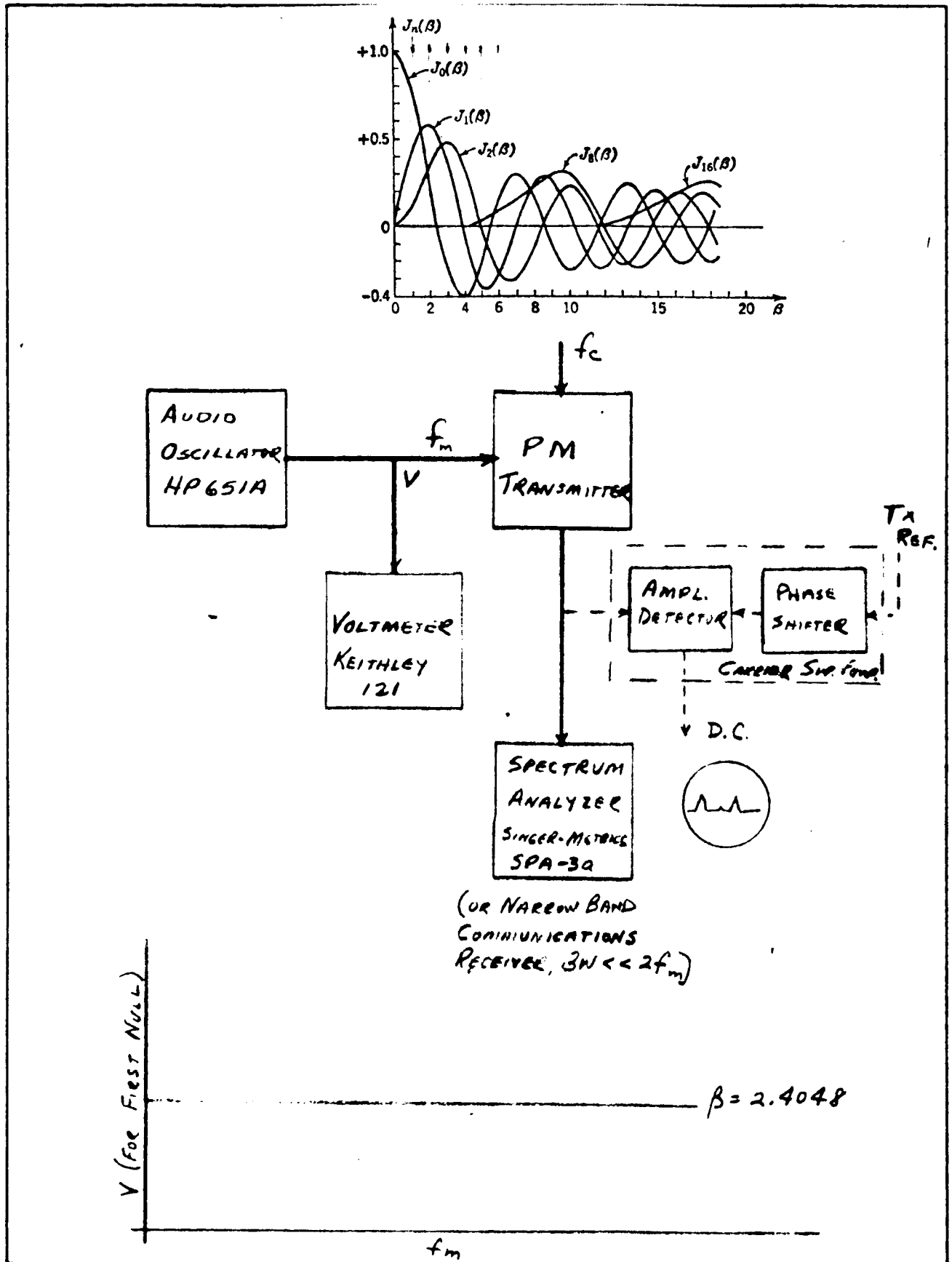
27

Figure 6. Test Setup for Frequency Response & Sensitivity

For this method to give accurate results, the incidental AM must be low as incidental AM on a PM spectrum increases the amplitude of one sideband and decreases the amplitude of the other.

For this reason, these tests will also be made with an available standard demodulator, the Marconi Modem Test Set, NQ-26A. This demodulator is sufficiently accurate to determine if the transmitter meets the required performance. For this test a conversion to the frequency of the test set (70 mc) is required. When the standard demodulator is used, its output is the modulating frequency plus any distortion products at a level proportional to β.

b. Phase Modulator

    (1) Frequency Response

    (2) Phase Deviation

Both of these items are checked in C1a(4).

    (3) Deviation Linearity

A qualitative measure of the distortion will be obtained by use of the arrangement in figure 6. This shows up as a greater number of sidebands than should be there. However, this will only show distortion which is rather bad, say 5-10%.

A more accurate measure of distortion is by use of the two tone test. In this test, figure 7, the transmitter will be modulated with two tones, each within the bandwidth, and the output observed by means of the standard demodulator and spectrum analyzer (or a spectrum display).

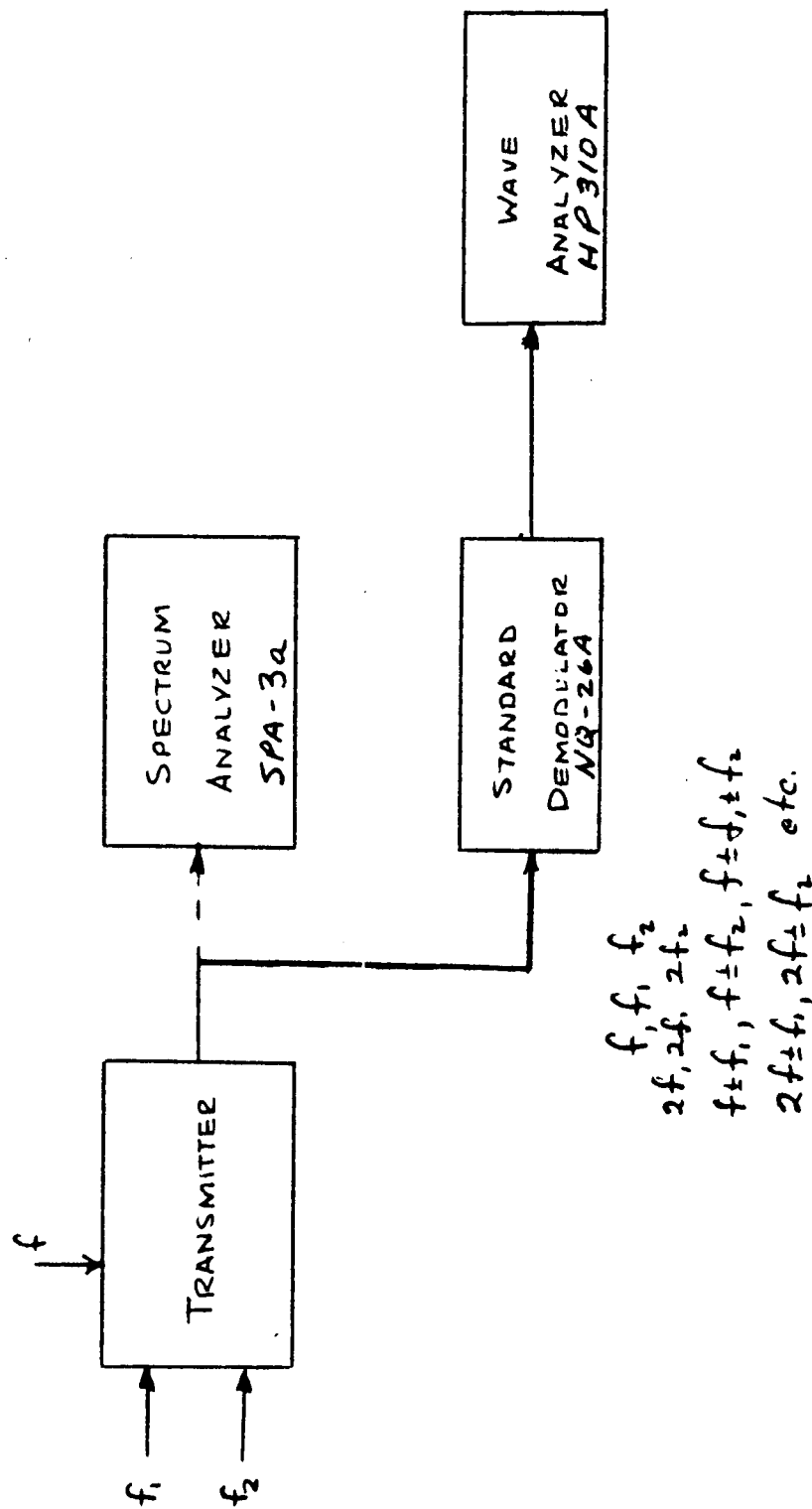   * Specifications on this set are itemized at the end of this section.

Figure 7. Deviation Linearity

$$f_1, f_1, f_2$$
$$2f_1, 2f_2, 2f_2$$
$$f \pm f_1, f \pm f_2, f \pm f_1 \pm f_2$$
$$2f \pm f, 2f \pm f_2 \quad etc.$$

All intermodulation components produced by the two tones can be seen and evaluated in terms of the amplitude of the undesired signal required to give a specified output compared with the amplitude of the desired signal to give the same amplitude. Thus, if an image voltage must be 100 times as strong as the desired signal to produce a given output, then the image discrimination is 40db.

With respect to the phase modulator, the goal of this measurement is to determine if the intermodulation and spurious products are down -46db (as noted in the PM modulator design). Using the Hewlett Packard 310 Spectrum Analyzer, a measurement accuracy of 1.0db appears practical. It will be necessary to do the two tone test with two or three pair of tones and for two or three different modulation indices in order to obtain a good measure of distortion.

(4) Incidental AM

Incidental AM will be checked by observation of the output of the transmitter on a scope (figure 3) for several deviations and modulating frequencies. Other methods, such as a spectrum analyzer and envelope detector will also be used as a check. These methods will give an indication of the presence of incidental AM with about 2% resolution. If a more accurate indication is required, an AM receiver calibrated for definite amplitude modulations will be used.

c. Amplitude Modulator

1. Frequency Response

Response of the modulator will be measured by putting known tones into the modulator and envelope detecting the output of the transmitter,
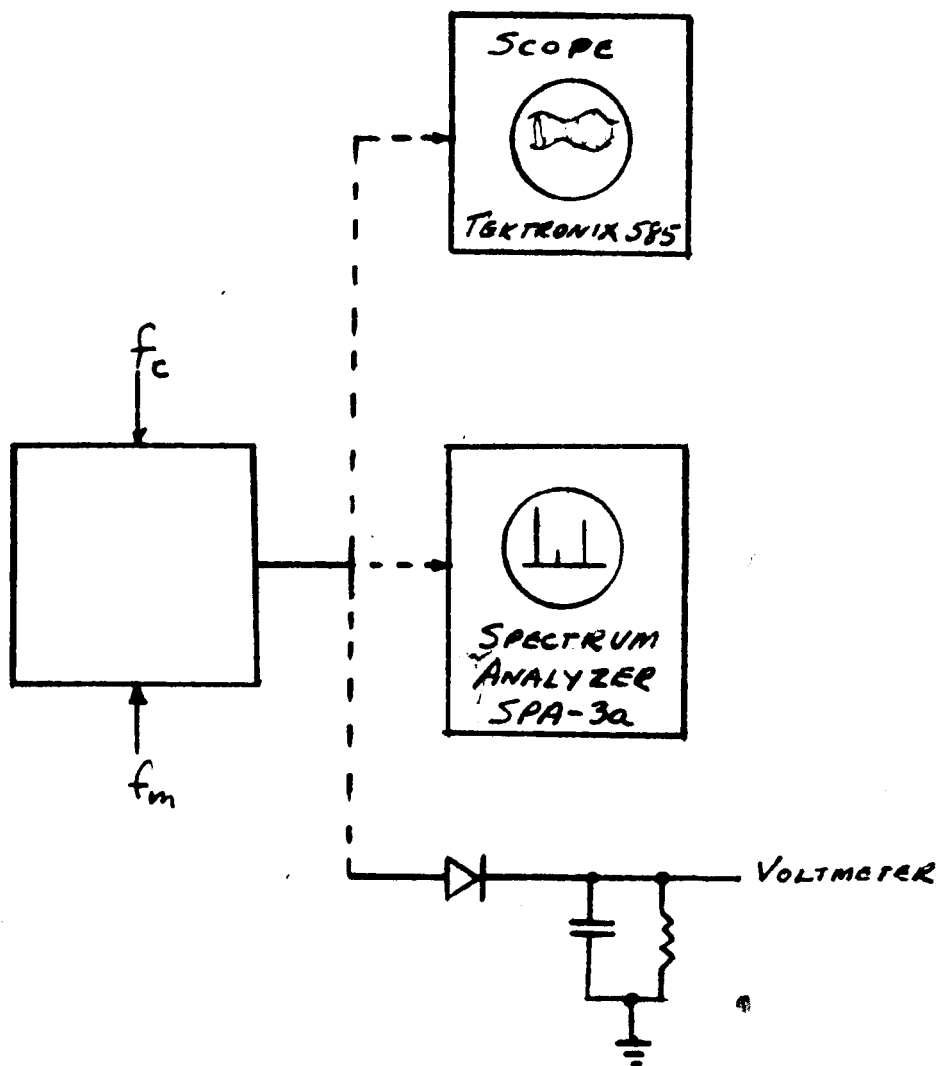
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Figure 8. Incidental AM

figure 9. As f is varied, with V_1 being fixed, the change of V_2 with

f gives a measure of response. This will be done for various modula-

tions up to 50%. With this, method, it is, of course, necessary to

know the characteristics of the envelope detector. Data supplied by

General Radio on the 874VQ indicate that its response is flat at these

frequencies. However, a spot calibration will be made by injection

of known frequencies and levels and measurement of the output with

a voltmeter.

    2. Per Cent Modulation

The degree of modulation will be determined by the setup shown in

figure 10. Changes in the level of V_1 change the percent modulation.

With this type of measurement, an accuracy of 10% is probable.

    (3) Modulator Linearity

Linearity will be determined by the two tone test already discussed.

    (4) Incidental FM & PM

Incidental FM and PM will be determined by monitoring the output

of the transmitter with the standard demodulator, figure 11. The

presence of an output and the frequency at which it occurs is a

measure of incidental angle modulation.

2. PM Receiver

    a. General

Once the PM transmitter has been fully tested, it will be used

as a test set for checking out the PM receiver. As with the transmitter,

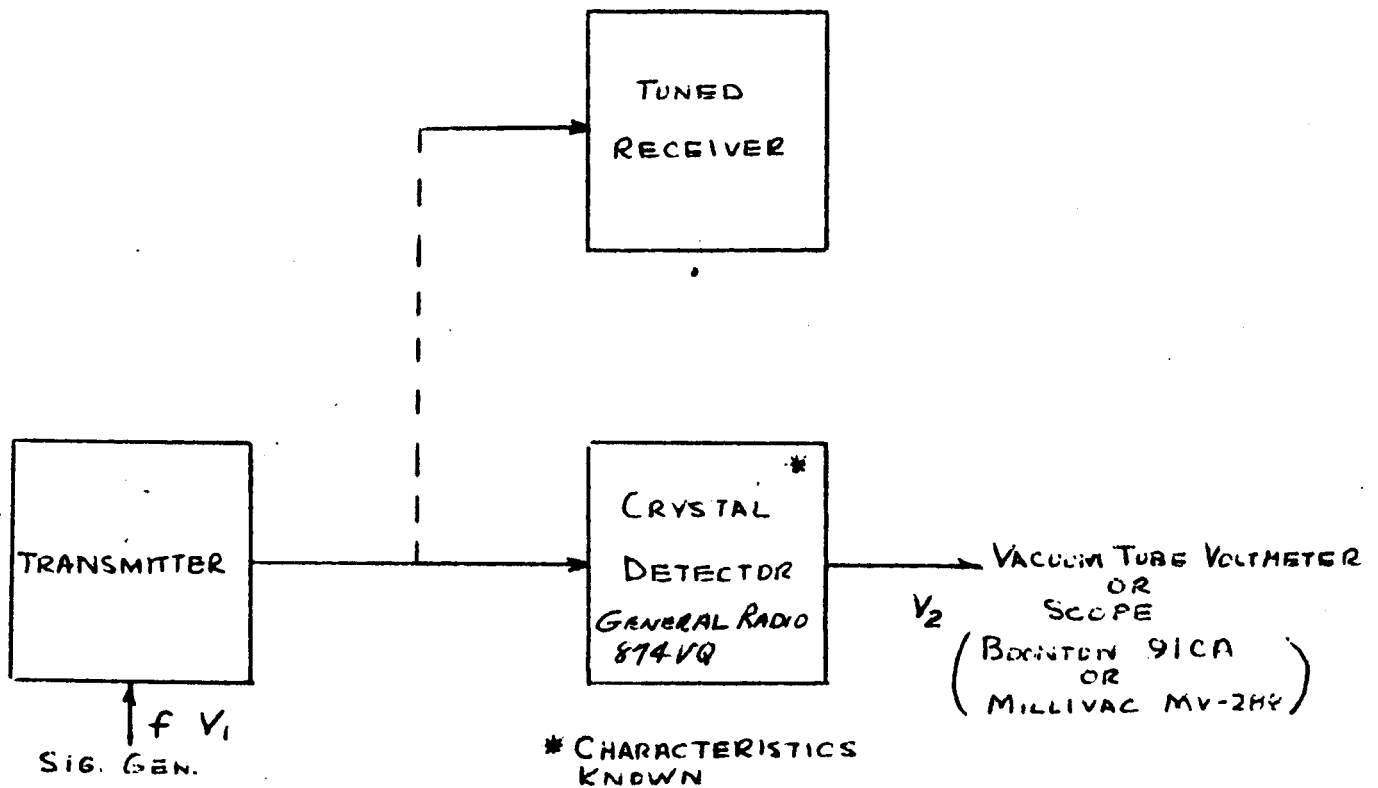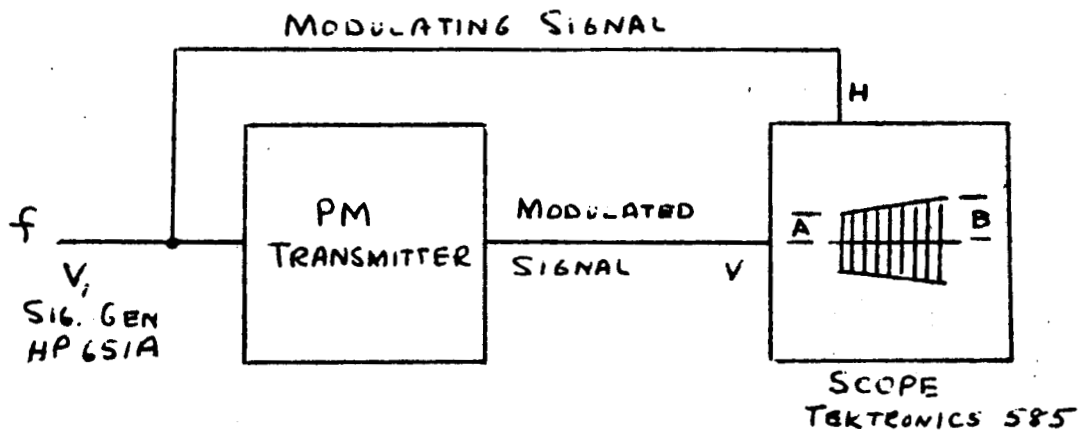input/output impedances and levels will be measured.
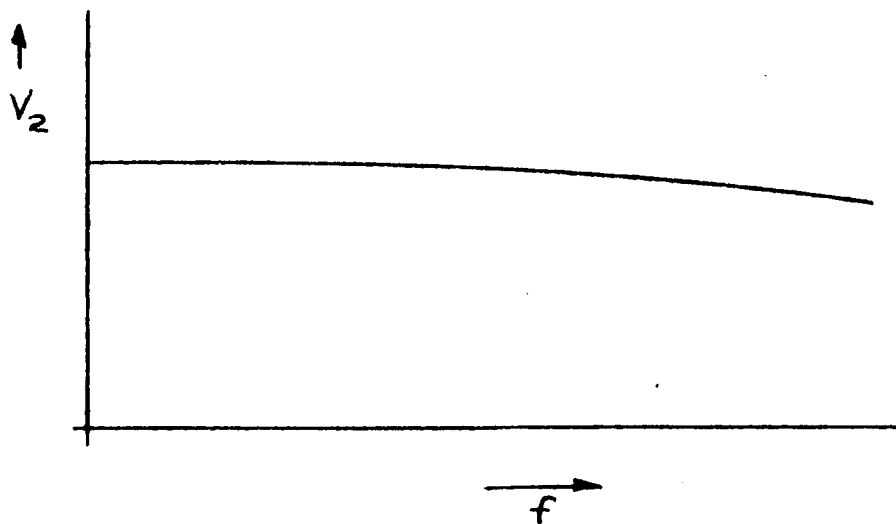
Figure 9. Frequency Response

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AMPLITUDE MODULATION $\quad m = \dfrac{B-A}{B+A}$
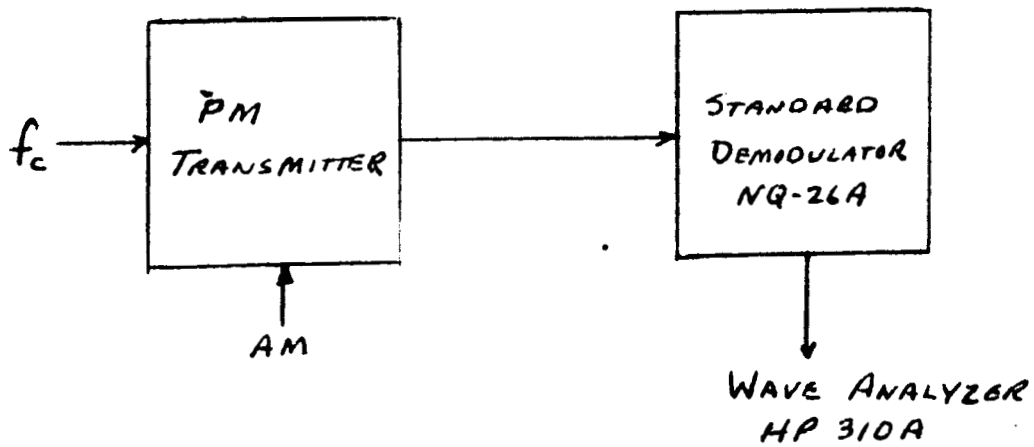
Figure 10. Percent Modulation

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Figure 11.   Incidental FM and PM

b. Input Amplifier

(1) Bandwidth

An initial measurement of the response will be made with swept frequency techniques. Final measurement of response will be made by injecting known frequencies across the band and measuring the output with the Weinschel dual channel setup as shown in figure 12. As shown, the rf signal is divided into two channels and the detected outputs of both channels are amplified and balanced to zero in the Synchronous Differential Null Detector (ND-2). When the amplifier to be tested is inserted, audio attenuation is changed in the BA-5 to keep the signal levels at the ND-2 balanced and constant. The attenuation is then equal to the difference in the BA-5 settings. Measurement accuracies well within the specified requirements of $\pm$ .25db can be obtained with this method.

(2) Phase Linearity

This will be tested as part of the receiver fidelity test. However, a preliminary check of linearity will be made by means of the two tone test.

c. Voltage Controlled Oscillator

(1) Frequency

The frequency will be verified with a counter to an accuracy of $\pm$ 1 count $\pm$ 3 parts in 10^9/day with the HP5245L.

(2) Stability

The stability will be checked as part of the overall stability of the air. A preliminary check of stability will be obtained by use of the HP5245L counter and operation for an 8 hour period.
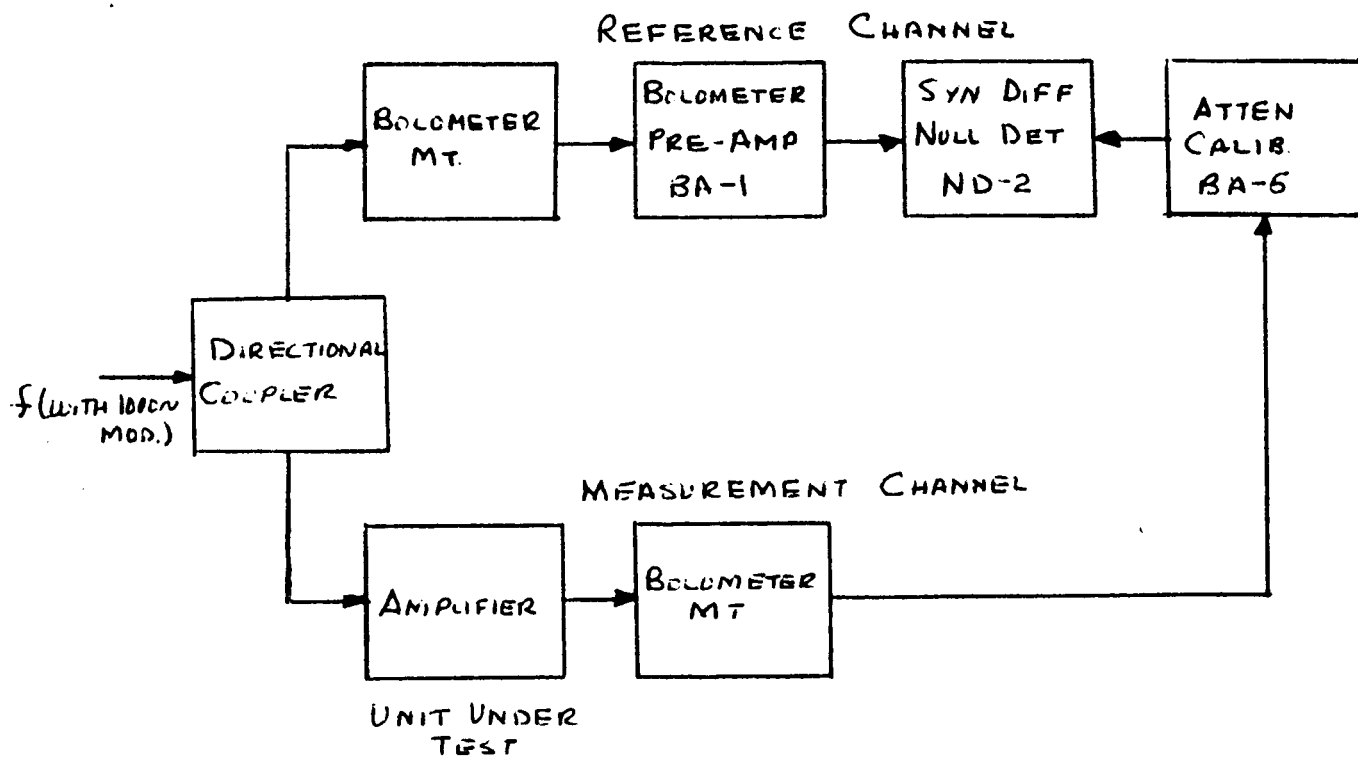
37

REFERENCE CHANNEL

BOLOMETER MT.

BOLOMETER PRE-AMP BA-1

SYN DIFF NULL DET ND-2

ATTEN CALIB. BA-6

DIRECTIONAL COUPLER

f (WITH 1000∿ MOD.)

MEASUREMENT CHANNEL

AMPLIFIER

BOLOMETER MT

UNIT UNDER TEST

Figure 11.   Input Amplifier Response

(3) Manual Tuning - demonstration of a capability

(4) Locked Condition - demonstration of a capability

d. Balanced Modulator

(1) Carrier and spurious rejection

Carrier and spurious rejection will be determined (figure 13) by feeding the carrier and a known tone f into the modulator and observing the output of the modulator with a spectrum analyzer with a resolution greater than 2f. An amplitude accuracy of 1db is probable. Since the output frequencies will bear simple integral relationships with the input frequencies, the frequency accuracy is that of the input frequencies. A search will be made for other spurious outputs. In this case, the HP5245L counter can be used to check any marker frequencies.

e. IF Amplifiers

(1) Frequency response

The response will be checked with the Weinschel Dual channel setup as shown in figure 12.

(2) Phase response

Phase response will be measured by use of one of the 10mc phase detectors which will be built and whose phase response (volts/degree) will be known, figure 14.

f. Reference Oscillator

(1) Frequency and phase stability

This will be checked as part of the stability tests of the transmitter/receiver pair. Preliminary tests will be made with the HP5245L frequency counter.
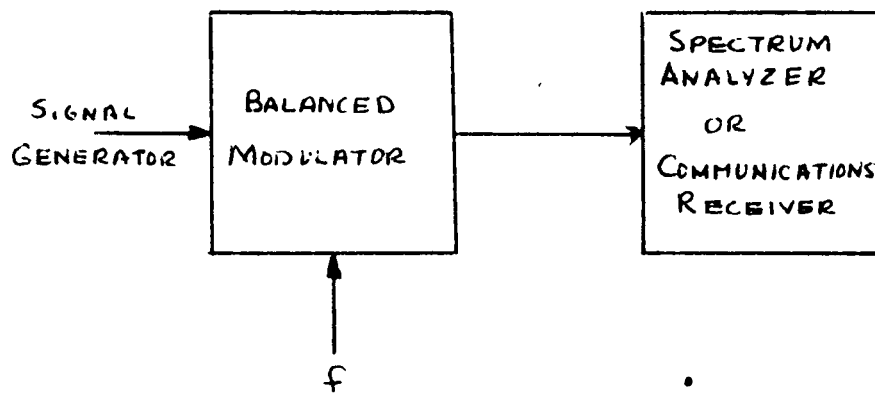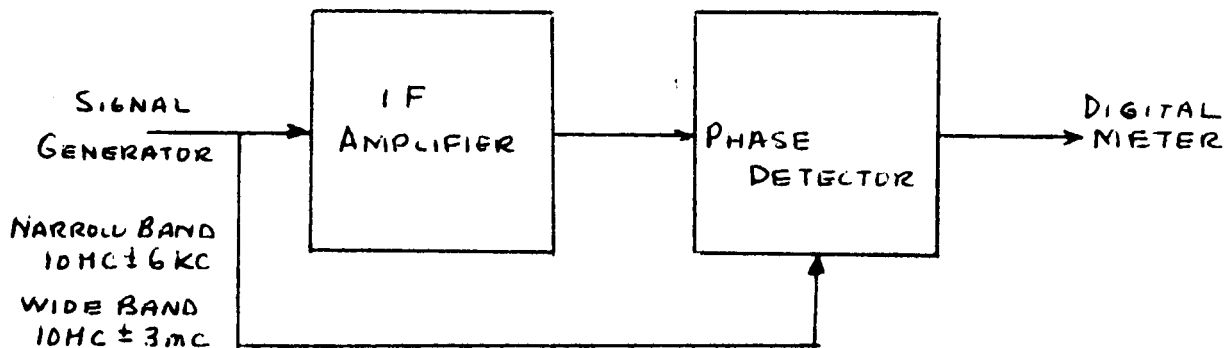
Figure 13. Balanced Modulator

SIGNAL
GENERATOR

NARROW BAND
10 MC ± 6 KC

WIDE BAND
10 MC ± 3 MC

IF
AMPLIFIER

PHASE
DETECTOR

DIGITAL
METER

Figure 14. Phase Response of IF Amplifiers

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g. Phase Detectors

(1) Bandwidth (Figure 15)

Open the phase loop, vary the input frequency and measure the output of the phase detector as a function of the difference between the input frequency and the VCO quiescent frequency. The beat frequency will be measured with a counter, the amplitude with true r.m.s. voltmeter or scope. Forecast measurement accuracy, 2%.

(2) Fidelity

Fidelity will be checked as part of the transmitter/receiver pair test. A measure of fidelity will be obtained from the response data.

(3) Gain constant (volts/radians)

The gain constant will be determined from the response data taken.

(4) Phase adjustment - demonstration of a capability

h. Phase Loop

(1) Gain

The gain of the individual loop parameters will be determined and then the loop gain calculated ($GAIN \ Ar \ /rad/_{sec} = K_A K_{vco}, K_\phi \alpha$). In addition, the loop gain will be measured by the method shown in figure 16. An error signal is introduced into the loop with a low frequency function generator and e_o, e_1 and e_2 measured with a scope. Then

$$\frac{error}{e_1} = \frac{e_2}{e_1} = \frac{1}{1+G(s)}$$

can be plotted as a function of frequency. Then $\frac{1}{\frac{1}{1+G(s)}} \approx G(s) \ for \ G(s) >> 1$

(a) Static Phase Error (figure 17)

The static phase error will be measured by measuring

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Figure 15. Phase Detector Bandwidth

SKETCH SHEET
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SIGNAL INPUT → BALANCED MODULATOR → IF → PHASE DETECTOR

REFERENCE OSCILLATOR

VCO ← LOOP FILTER

e_0

e_2, R_2 e_1, R_1

FUNCTION GENERATOR WAVETEK 103
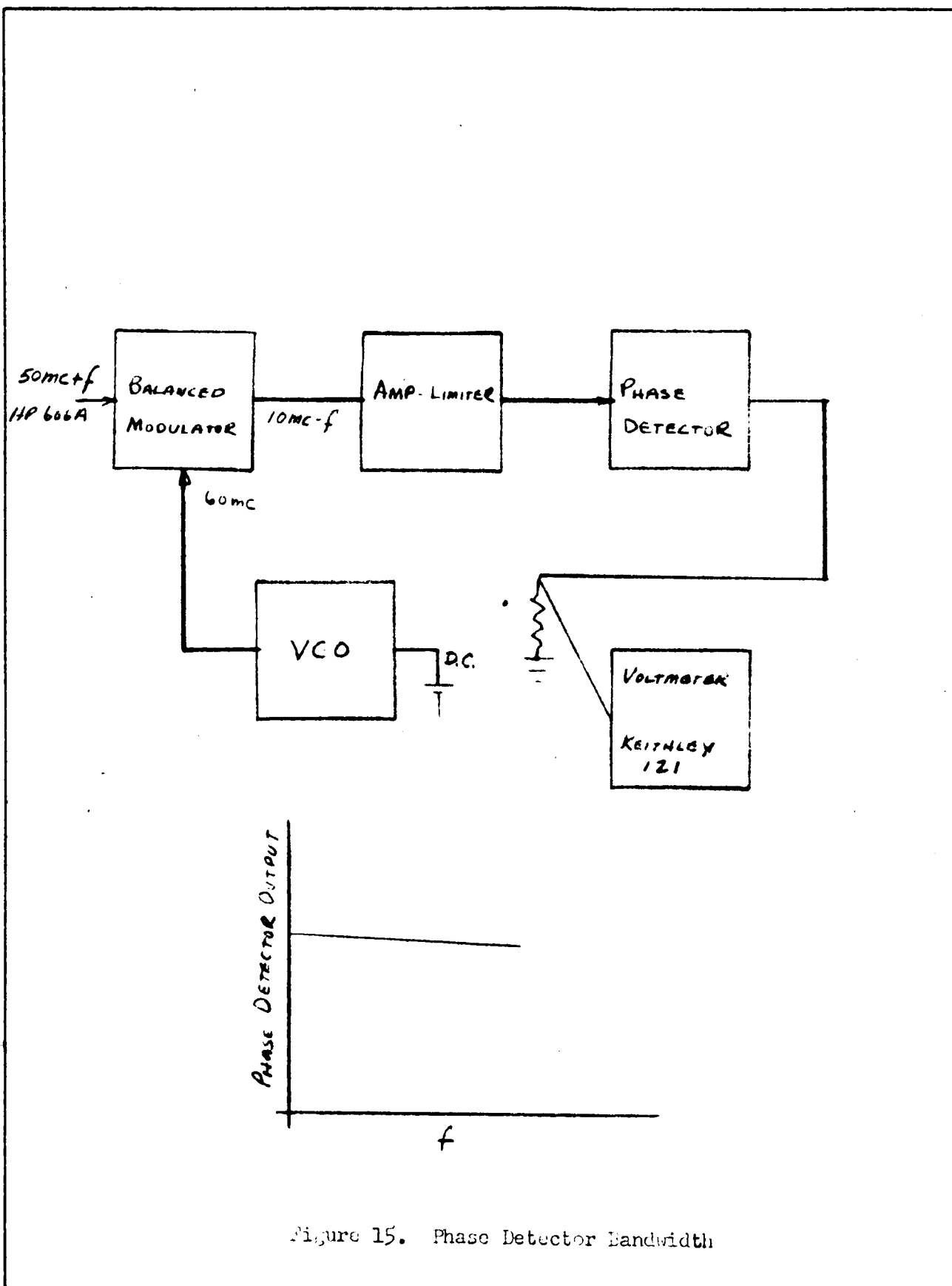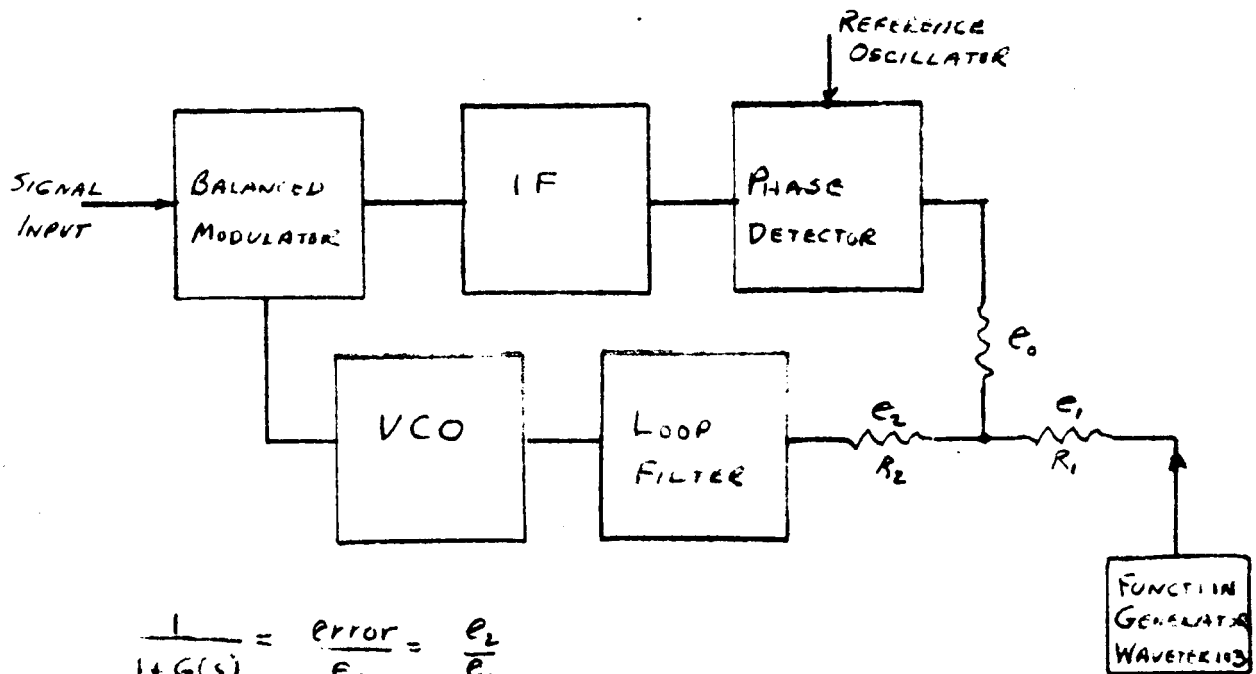
$$\frac{1}{1+G(s)} = \frac{error}{e_1} = \frac{e_2}{e_1}$$

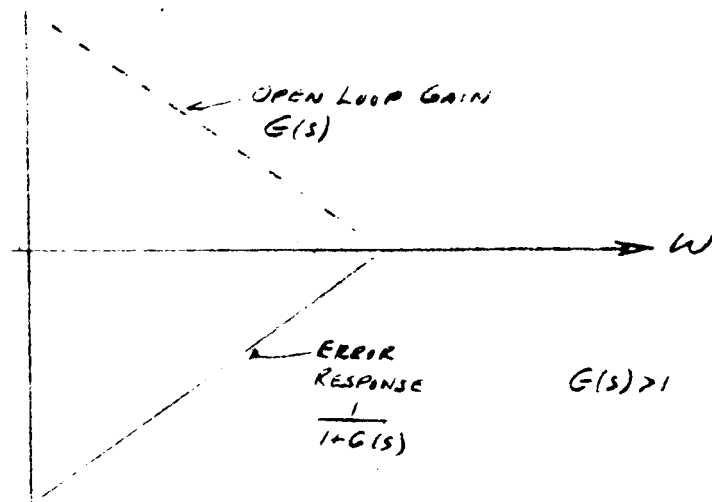$$LOOP\ GAIN = \frac{1}{\frac{1}{1+G(s)}} = G(s) \quad , \quad G(s) >> 1$$

OPEN LOOP GAIN $G(s)$

ω

ERROR RESPONSE $\frac{1}{1+G(s)}$ $G(s) > 1$

Figure 10. Loop Gain

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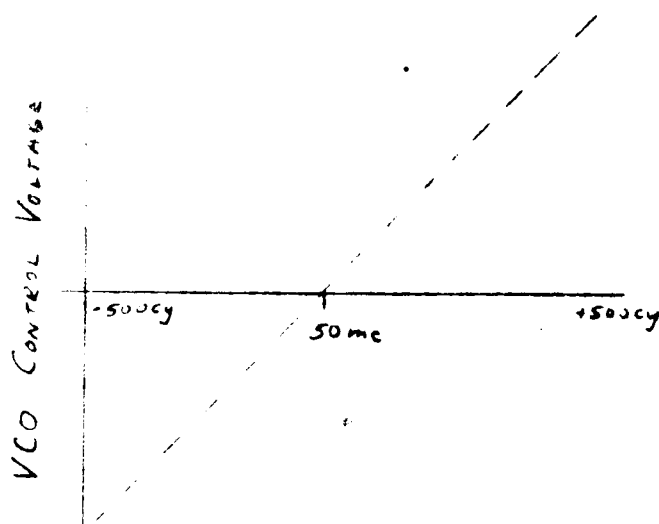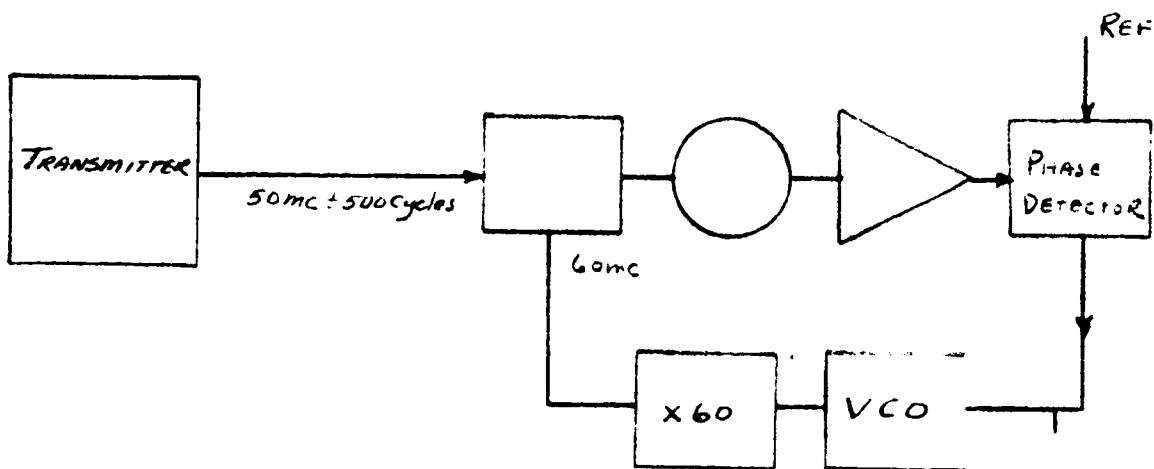
Figure 17. Static Phase Error Gain
Stability

at the output of the phase detector as the transmitter frequency is adjusted over the 500 cycle tuning range.

(b) Gain Stability

Will be determined by measuring the VCO control voltage as a function of the change of the transmitter frequency. The nearest straight line is the nominal. Since this voltage can be measured with a digital voltmeter, an accuracy of 1% is probable.

(2) Filter Bandwidths

Filter bandwidths will be measured by the setup shown in Figure 16.

i. Amplitude Detectors

(1) Bandwidth

The bandwidth will be checked by feeding known signals into the detector and noting any change in level, with changes in frequency. This will be done at several input levels. See Figure 18.

(2) Linearity

(a) Static

Static linearity will be determined by connecting the transmitter to the receiver with the ACC disabled, varying the transmitter carrier level and measuring the change with a d.c. meter on the output of the AM detector (figure 19a). The measurement accuracy depends on the accuracy of the attenuator and the digital voltmeter. In this case, the Weinschel attenuators and the HP3400A digital voltmeter will be used. The attenuators are accurate to a .1db while the digital
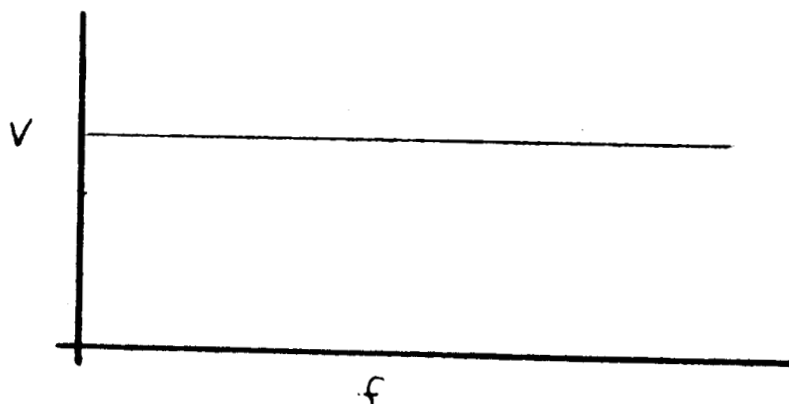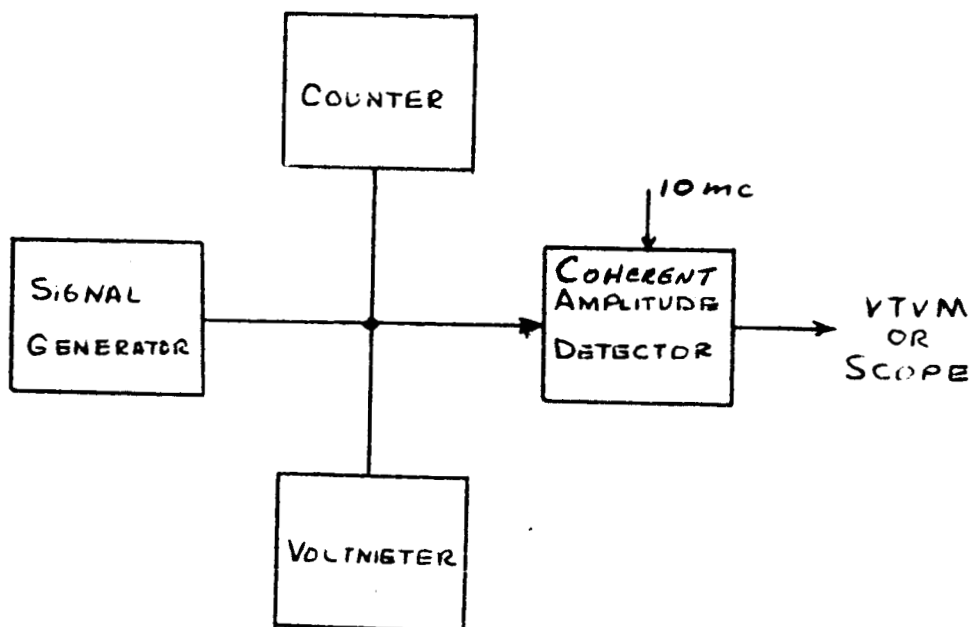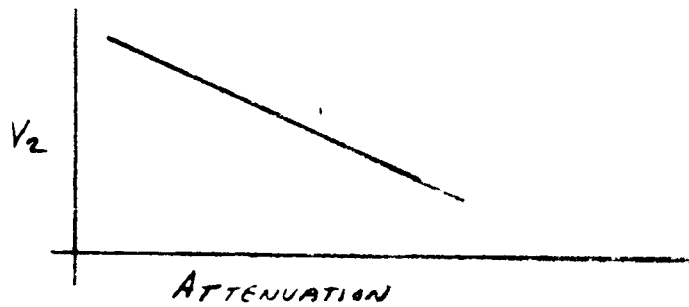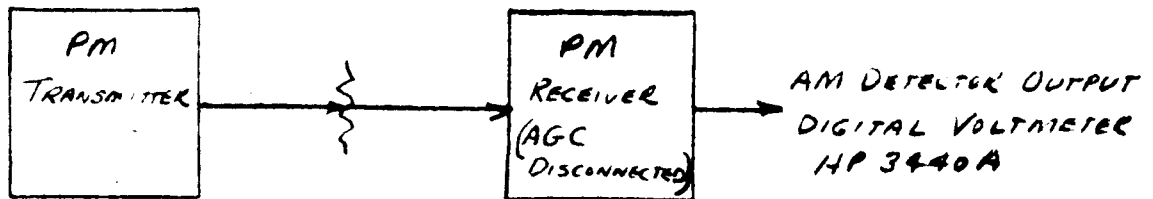
46

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Figure 16. Amplitude Detector Bandwidth
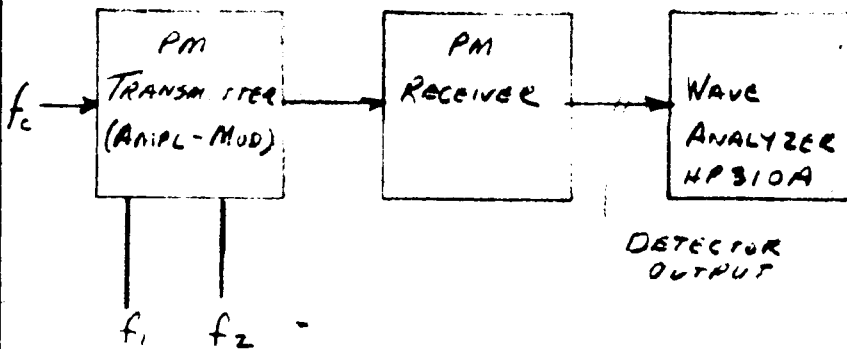
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STATIC

(a)

DYNAMIC

(b)

Figure 19. Amplitude Detector Linearity

voltmeter is accurate to .05%. On this basis, a measurement accuracy of less than 1% is probable.

(b) Dynamic

Dynamic linearity (figure 19b) will be determined by the two tone test previously explained. Probable accuracy ,1db.

(3) Phase adjustment and manual gain control

This is a demonstration of capability.

j. AGC

(1) Loop Gain (figure 20)

Vary the input level of receiver by means of precision attenuator. Measure output of narrowband IF amplifier with true rms voltmeter and scope. Measurement accuracy, probably less than 5%.

(2) Filters will be measured by the setup shown in figure 16.

k. Offset Frequency

The offset frequency will be checked with the HP5245L frequency counter.

l. DC & AC Isolation Amplifiers & Predetection Playback

This is a demonstration of capability.

3. FM Transmitter/Receiver Pair

a. Phase Stability

Phase stability will be measured as outlined in the synthesizer test, Section B1 (figure 3 & 4). With an unmodulated carrier input, a scope is used to observe the jitter on the output of the phase detector.

b. Fidelity

Fidelity will be determined by means of the two tone test previously described for checking the transmitter only. Here, the transmitter/receiver pair will be used instead of the individual item.

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4. Phase Noise Instrumentation - This is covered in another section of the report.

D. FM Transmitter/Receiver

1. F.M. Transmitter

a. General

In a number of cases the same tests performed on the PM transmitter will be used to check out the FM transmitter. In those cases where this can be done, the appropriate section is noted.

(1) Transmitter Center Frequency

This is a demonstration of capability and will be verified with the HP5245L frequency counter to the accuracy of the counter.

(2) Power Output

The power output will be checked with a power meter.

(3) Frequency Multipliers and Reference Output

These are covered in section B.

(4) AFC Operation

This is a demonstration of capability.

(5) Bandwidth

This will be measured in the same way as for the PM transmitter. See Section Cla(4). In this case, (figure 21), a change in modulation frequency, f_m, requires a corresponding change in the deviation, Δf, in order to maintain the same B (for FM, $\beta = \dfrac{\Delta f}{f_m}$). The response curve should accordingly be a line with a constant slope, $\dfrac{\Delta V}{\Delta f_m} = C.$
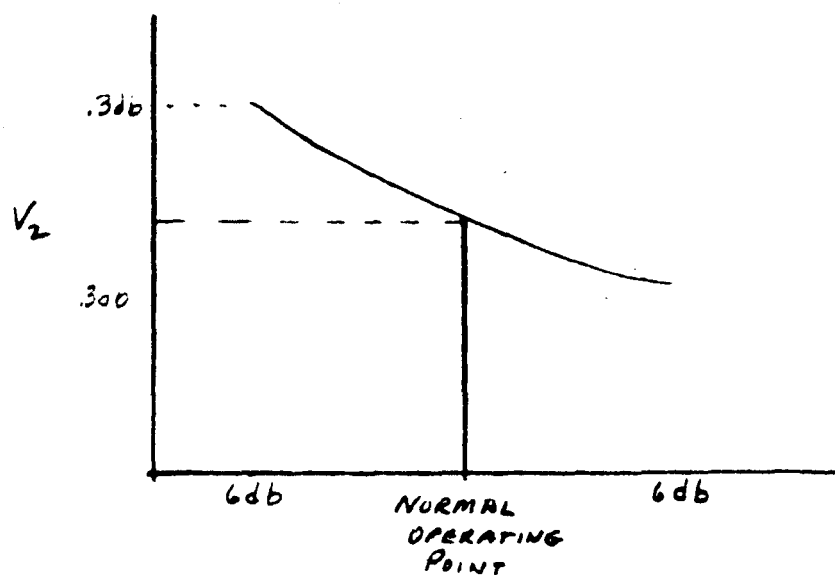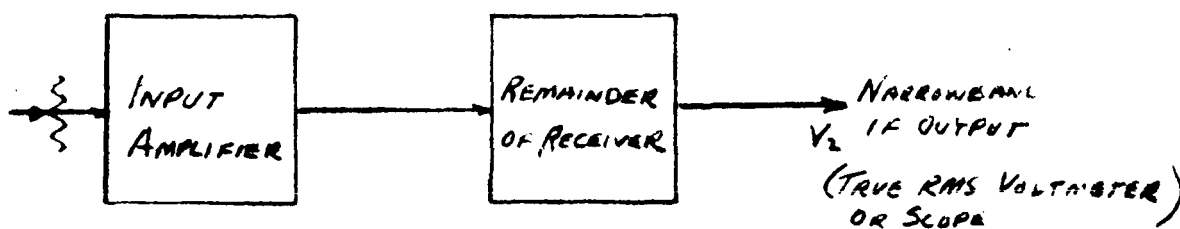
50

SKETCH SHEET
FORM 28577

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INPUT AMPLIFIER → REMAINDER OF RECEIVER → NARROWBAND V_2 IF OUTPUT (TRUE RMS VOLTMETER) OR SCOPE

Figure 20. AGC Loop Gain

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65-335 APPK

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f_c

| AUDIO OSCILLATOR HP651A | | FM TRANSMITTER |

f_m

V

| VOLTMETER KEITHLEY 121 |

| SPECTRUM ANALYZER SPA-3a |

i

$\beta = 2.4048$
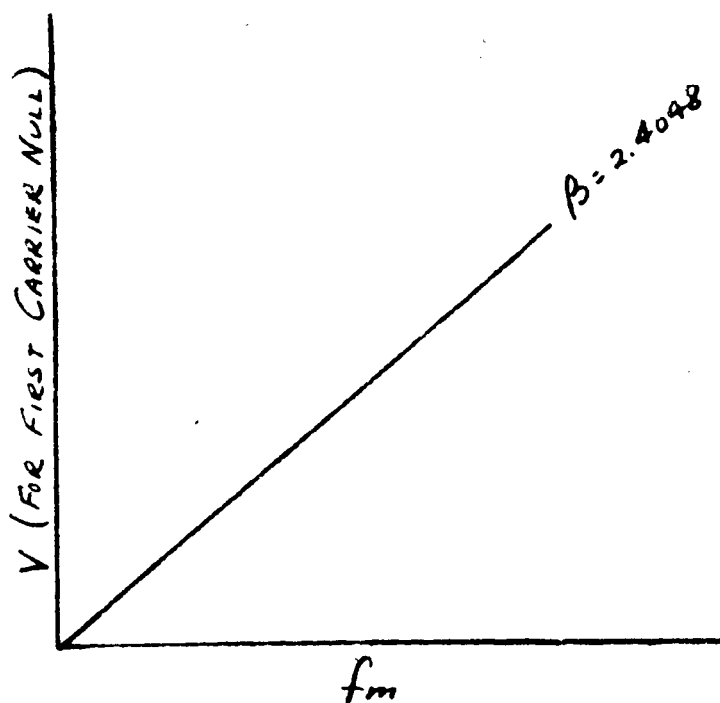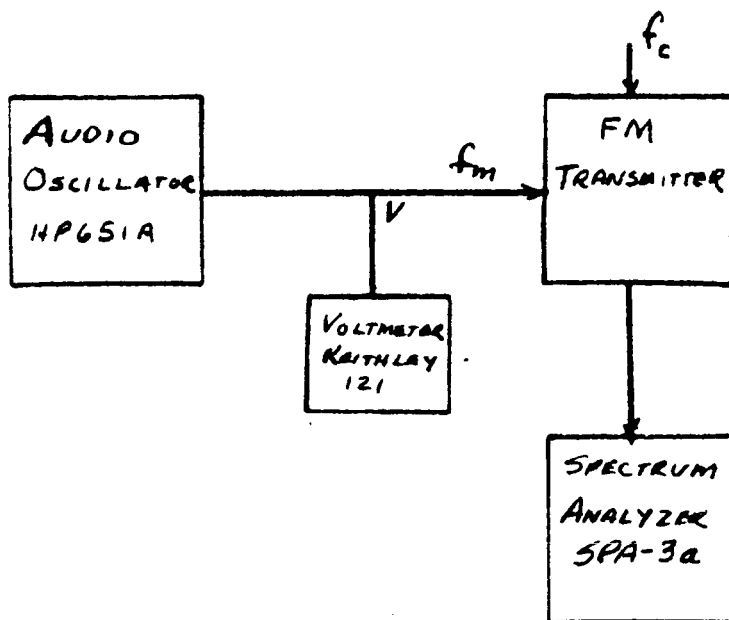
V (FOR FIRST CARRIER NULL)

f_m

Figure 21.   Bandwidth

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b. Frequency Modulator

    (1) Response and Sensitivity

    (2) Frequency Deviation

    (3) Deviation Linearity

    (4) Incidental AM

The same test procedure will be used here as for the Phase Modulator in the PM Transmitter.

c. Amplitude Modulator

The same test procedure will be used here as for the amplitude modulator in the PM Transmitter.

d. FM Receivers

    a. General

Much the same condition for the FM receiver applies as for the FM transmitter in that a number of the tests used for the PM receiver will also be used for the FM receiver.

b.* Input Filter

    (1) Bandwidth

The bandwidth will be determined by the method covered in C2b.

    (2) Amplitude Characteristics

The amplitude characteristics will be determined during the bandwidth test.

    (3) Phase Linearity

The phase linearity will be checked as part of the pair test.

c.* Limiter

    (1) Dynamic Range

The static range of the limiter will be measured by the setup shown in figure 22. The output voltage is monitored as a function of input voltage. The dynamic range will be checked as part of the pair tests by observation of the response of the receiver to AM at different signal levels.

(2) Output Waveform

The output waveform will be examined by means of the Tektronics #585 scope.

d. Conventional FM Detector

This will be tested as part of the pair test. However, a preliminary two tone test will be made on it.

e. Phase Lock FM Detector

(1) Voltage Controlled Oscillator

The frequency of the voltage controlled oscillator will be checked with the HP52452 counter. The deviation capability will be verified by use of varying d.c. levels and measurement of the frequency excursion of the oscillator by means of the counter. The other characteristics will be verified in the test of the Tx/Rx pair.

(2) Phase Detector

Phase detector will be tested as in C2g.

(3) Loop Gain

Same as C2h(1)
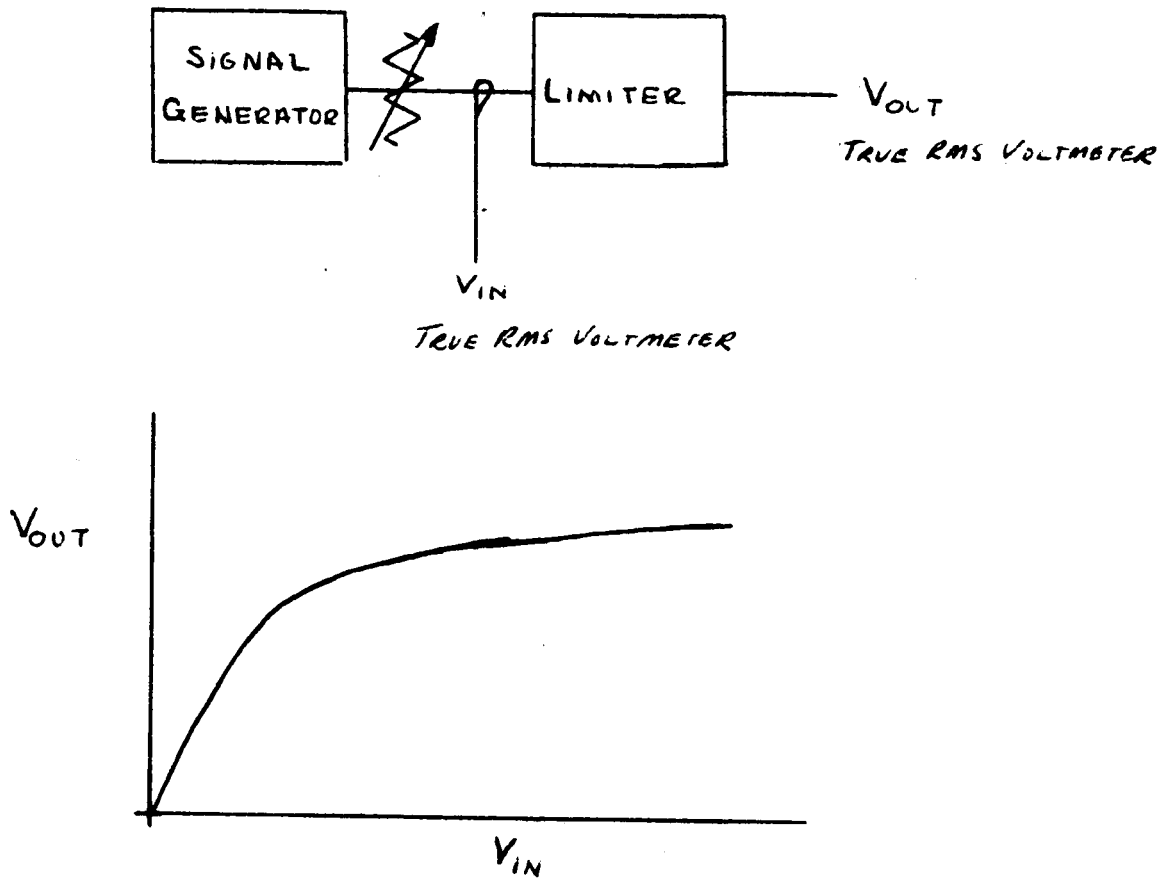
(4) Loop Filter

Same as C2h(2)

Figure 22. Limiter Static Range

f. Output Filter

   (1) Bandwidth

   Bandwidth will be checked by monitoring output vs. input.

g. Offset Frequency

   This will be verified with the HP52452 frequency counter.

h. Balanced Modulator

   This will be checked as in C2d.

i. D.C. and A.C. Isolation Amplifiers and FM Predetection Playback

   Demonstration of capability.

3. FM Transmitter/Receiver Pair

   a. Frequency Stability

   The method for measuring the residual FM characteristics of
the transmitter-receiver pair is illustrated in figure 23. For a certain
fm, adjust the level until a β of 2.4048 is attained. At this point,
no energy exists in the carrier. Record the value of V_2 . The rms
deviation corresponding to V_2 is .707 x 2.4048 x fm. Then, remove
the modulating-frequency by opening the switch. Record the resulting
value of V_2 and call it V_2' . Then

$$\Delta f_n = \frac{V_2'}{V_2} \times .707 \times 2.4048 \times f_m$$

$$If \quad f_m = 50 KC, \ then \ \Delta f_n = \frac{V_2'}{V_2} \times 85010$$

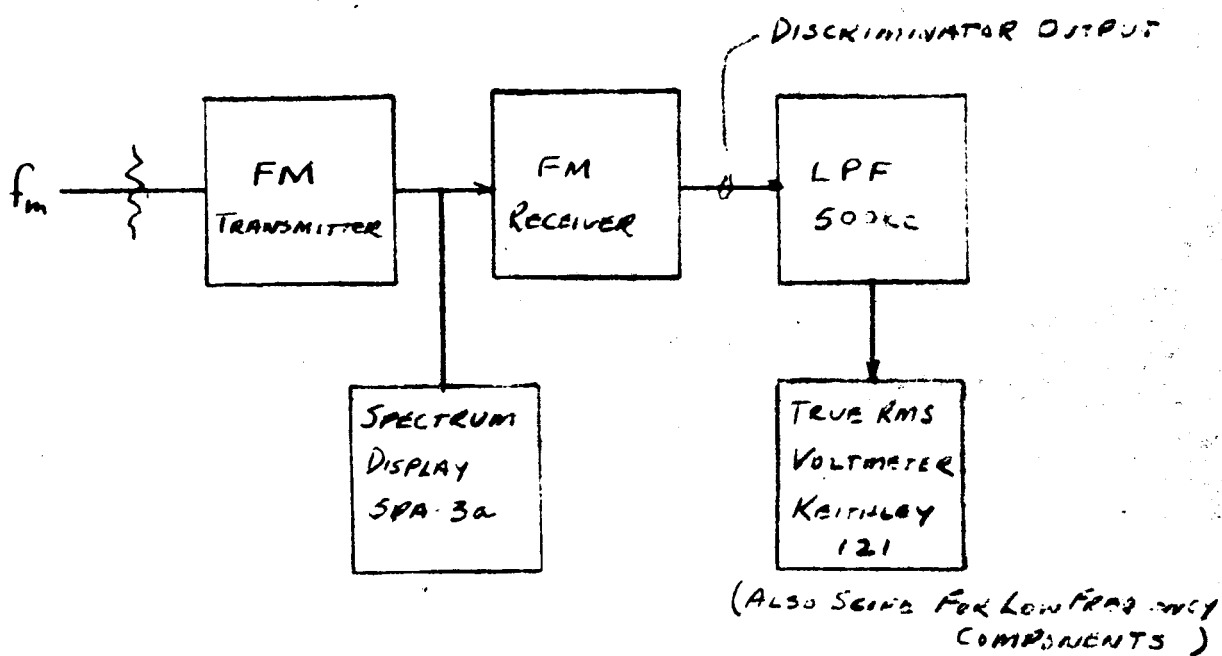65-335 App K

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Figure 23. Frequency Stability Measurement

This test will be made in the AFC and non AFC mode. Probable measurement accuracy, 10%. It is worthwhile noting that it is anticipated that the 20 cps rms residual FM requirement in the non-AFC mode can be met for only a short time interval of a second.

   (2) Static Linearity

   The static linearity characteristics of the transmitter-receiver pair will be obtained by feeding a series of d.c. voltages into the transmitter and recording their values at the output of the receiver figure 24. Since this measurement is made in the non-AFC mode, drift may be a problem. Consequently, the zero reading will be checked after each reading. Probable accuracy using Fluke 801B Differential Voltimeter is less than 1%.

   (c) Dynamic Linearity

   The amount of harmonic distortion in the output signal is a direct measure of the degree of dynamic linearity. The two tone test as previously described will be used to check linearity. The Hewlett Packard 310A spectrum analyzer will be used to observe the output of the receiver and compare it to the modulation input to the transmitter.

E. Linear S/N Summer — This is covered in Section IV of the report.

F. Miscellaneous

   1. Purchased Instrumentation

   The purchased instrumentation will be tested sufficiently to indicate compliance with published data. This will be done by the Product Reliability Department - it is well equipped for this work as it has been set up to handle all calibration and standards certification for the Surface Division.
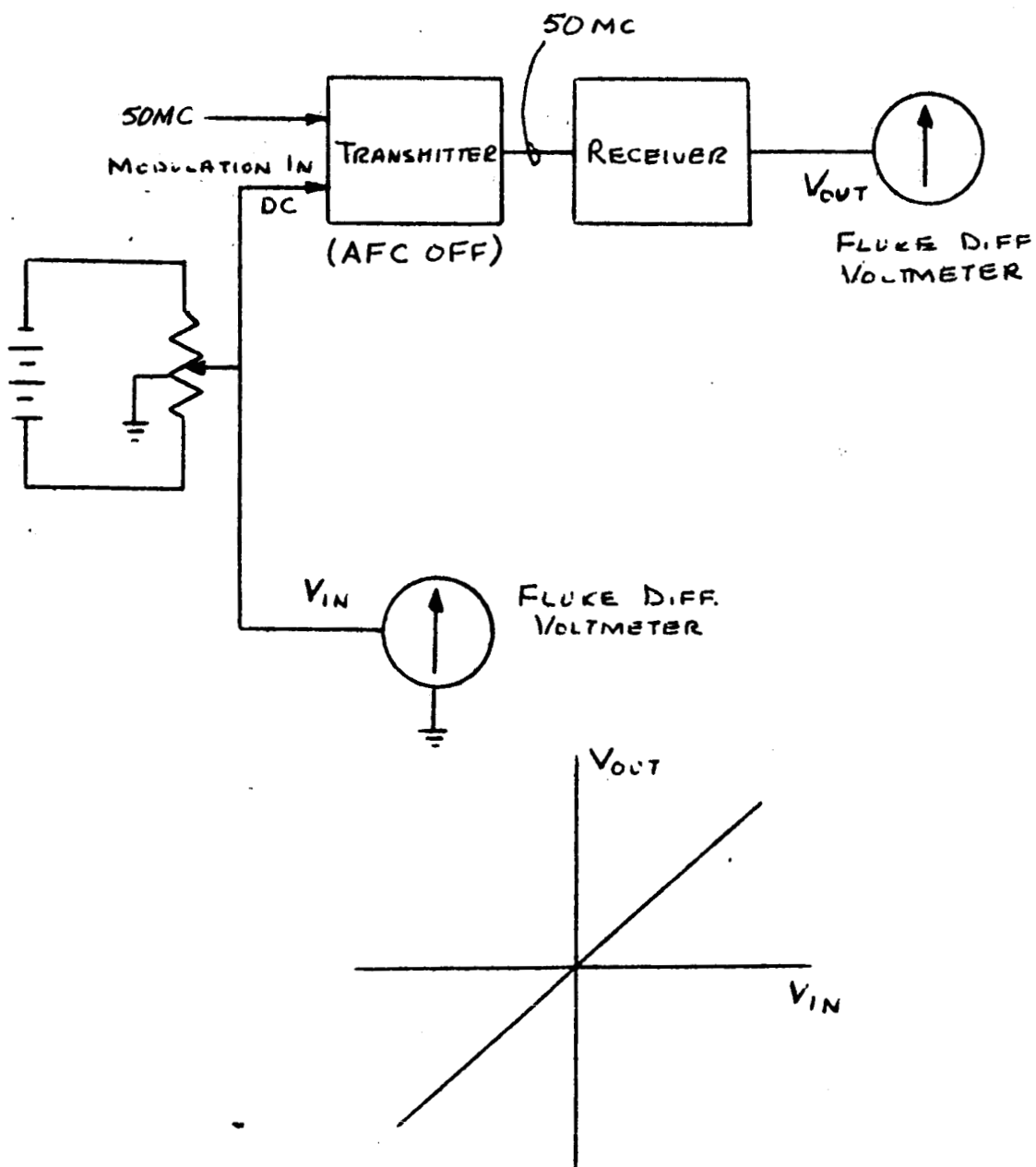
Figure 24 Static Linearity

2. Console Assembly Equipment

Bench tests of the power supplies and routine checks of the power distribution will be made during the course of assembly of the individual items in the console.

3. Interference

a. Coherent

It is assumed that coherent interference is referring to those signals existing in various parts of the system which are coherent with the desired signals and which, due to proximity or radiation, cause interference with the desired signal. Positioning of the parts and use of shielded assemblies and double shielded cables in critical areas will help considerably in eliminating this problem. Since the components will be tested prior to installation in the console, an indication of coherent interference will be obtained if results are different from that obtained prior to installation.

b. Spurious

Responses to spuriously generated internal signals will be determined as part of the normal tests on the transmitters and receivers for intermodulation and spurious. Tests for responses within the console to externally generated spurious signals cannot be made unless one has a knowledge of the environment in which the test console will work. As part of the design, shielded power line filters over the frequency range of operation will be installed in the incoming lines. Also a completely shielded enclosure with double shielded cables will be used. However, tests for the effect of externally generated radiation will have to be conducted at the time of installation of the equipment.

c. Radiated

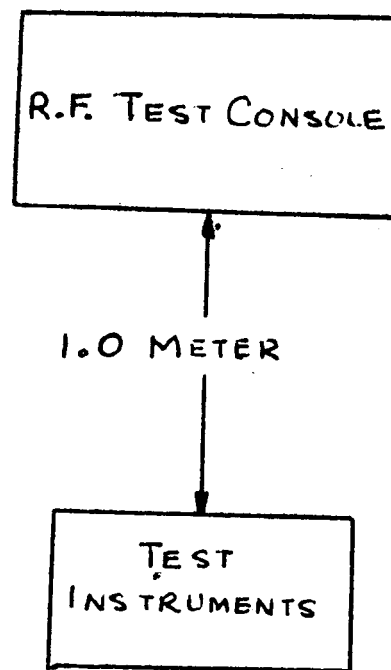It is assumed that the radiated interference figure of -150dbm

60

Figure 25. Radiated Interference Test

is -150 dbm per square centimeter as this is within the measurement range
of presently available interference measuring equipment. The equipment
(figure 25) is energized and adjusted for normal operation. Interference
measuring instruments (Studdart or Polarad) will be located in a position
of maximum RF pickup at a distance of one meter from the console. Measure-
ments will cover the range from 10 KC to 1.0 Gc. The entire band will be
scanned by continuously tuned interference measuring sets and interference
peaks, if any, will be measured and recorded. In addition, specific fre-
quencies, namely those intentionally generated inside the console will be
measured and recorded.

PERFORMANCE SPECIFICATION
CANADIAN MARCONI COMPANY
NQ-26A MODEM TEST SET

#163-915   DEMODULATOR

In the demodulator, a series of limiter-amplifier stages provides

gain stability and removes amplitude modulating noise components prior

to demodulation in a frequency discriminator. The final demodulator

stage is a discriminator feeding baseband information to the demodulator

output unit.

Demodulator Unit

Item	Value or Description

Limiters

Centre Frequency	70 mc
Bandwidth	± 10 mc within ± 0.25 db
Input Level	+ 3 dbm nominal
Input Impedance	75 ohms
Input Return Loss	Greater than 26 db ± 5 mc Greater than 20 db ± 10 mc Amplitude compression of a 70 mc carrier with 10% amplitude modulation is greater than 30 db for modulating frequencies 30 kc to 5 mc for nominal input level

Discriminator

Derivative	Within ± 0.1 db over ± 5 mc Within ± 1.0 db over ± 9 mc
Sensitivity	100 mv/mc ± 3 db
Sense	Type A - Increase in i-f frequency produces a positive going baseband output voltage Type B - Increase in i-f frequency produces a negative going baseband output voltage
Linearity (2 Tone Test)	60 db
Noise Power Ratio	55 db (60 kc to 2.5 mc)

Complete Unit

Baseband Frequency Response	0.5 cps to 5 mc within ± 1 db
Baseband Output	Matched to 1000 ohm resistive input of demodulator output unit.
Power Consumption	+ 160 vdc, regulated, at 75 ma + 150 vdc, unregulated, at 90 ma 12.6 vac at 0.9 amp 6.3 vdc at 1.5 amp
Mechanical	Standard printed board chassis Width: 4-1/2 inches Length: 16-1/2 inches Height: 2-1/2 inches (with tubes)
Tube Complement	11 7737

Demodulator Output Unit

Traffic Amplifier

    Output Level   -7 dbm/channel

    Maximum Gain   19 db $\pm$ 2 db

    Frequency Response   High Frequency: within $\pm$ 0.1 db up to 6 mc
                                        Low Frequency: within $\pm$ 1 db up to 8 mc;
                                                      less than 1% droop on a 60
                                                       cps square wave

    Input Impedance   1000 ohms resistive

    Output Impedance   75 ohms

    Output Return Loss   Greater than 26 db up to 5 mc
                                    Greater than 20 db up to 7 mc
                                    Greater than 17 db up to 8 mc